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BILATERAL INTEGRATIVE ACTION OF THE CEREBRAL CORTEX IN MAN IN VERBAL ASSOCIATION AND SENSORI-MOTOR COORDINATION

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I. INTRODUCTION

The two cerebral hemispheres in man are interconnected primarily by one of the most extensive bands of fibers of the nervous system, the corpus callosum, which, because of its size and its scope of projection in the cortical layers, very naturally has been thought to be significant in determining many complex mental processes. Psychological functions involving verbal association and memory have been assumed to be particularly dependent on this system of neurones. Sensori-motor activities demanding functional connections between the two sides of the brain are also typically held to require neural integration by means of the neurones of the corpus callosum. In the present study, it has been possible to employ the methods of the controlled experiment with human individuals in determining the functional significance of these intercortical neurones in the representative activities of the types mentioned.

The results to be reported are based upon preoperative and postoperative tests on individuals in whom the nerve bands connecting the two cortices were cut in order to control convulsions (**3**).

II. METHODS

I. *Behavior measurements.*—Determinations of response time were obtained on the following types of activities:

A. Response time for simple reactions to visual, auditory, and tactual stimuli. The response times for both right and left hands were secured for the visual and auditory stimuli. Ten measures of response time were made preoperatively and postoperatively for each type of reaction.

[1] The writer wishes to thank Dr. William P. Van Wagenen and Dr. Andrew J. Akelaitis for their helpful cooperation in making these experiments possible.

B. Response time for discriminative visual reactions. The design of this part of the experiment permitted separate measures for responses involving crossed and uncrossed hemispheric relations (presumed), right and left hands, right and left eyes, as well as separate measures for the two eyes or the hands in relation to both crossed and uncrossed reactions. For each type of reaction ten determinations of response time were made.

C. Response time in verbal association. Three types of association were measured; free word-association, opposites association, and part-whole association. One hundred test words were used in the free word-association tests and 20 test-words in each of the opposites and part-whole association tests.

II. *Apparatus.*—An apparatus was designed for this study which permitted making measurements as described above. The equipment consisted of standard reaction-time apparatus except for the parts used in analyzing discrimination reactions. A balanced relay circuit connected with proper keys, stimulus-producing devices, and an electric clock [2] constituted the main part of the system. The stimulus elements used in the studies of simple reactions consisted of a buzzer, a red light (one cm. in diameter), and a padded relay arm. The padded relay arm was arranged to stimulate the back of the left hand of the *S*.

In making the measurements on verbal association, voice keys [3] were employed in place of the *S*'s and *E*'s manually operated keys. These two types of keys could be switched in and out of the main circuit as desired.

The arrangement of the equipment for studies of discriminative visual reactions is shown in Fig. 1. Diagrammatic lines and figures are given to show the presumed anatomical relations

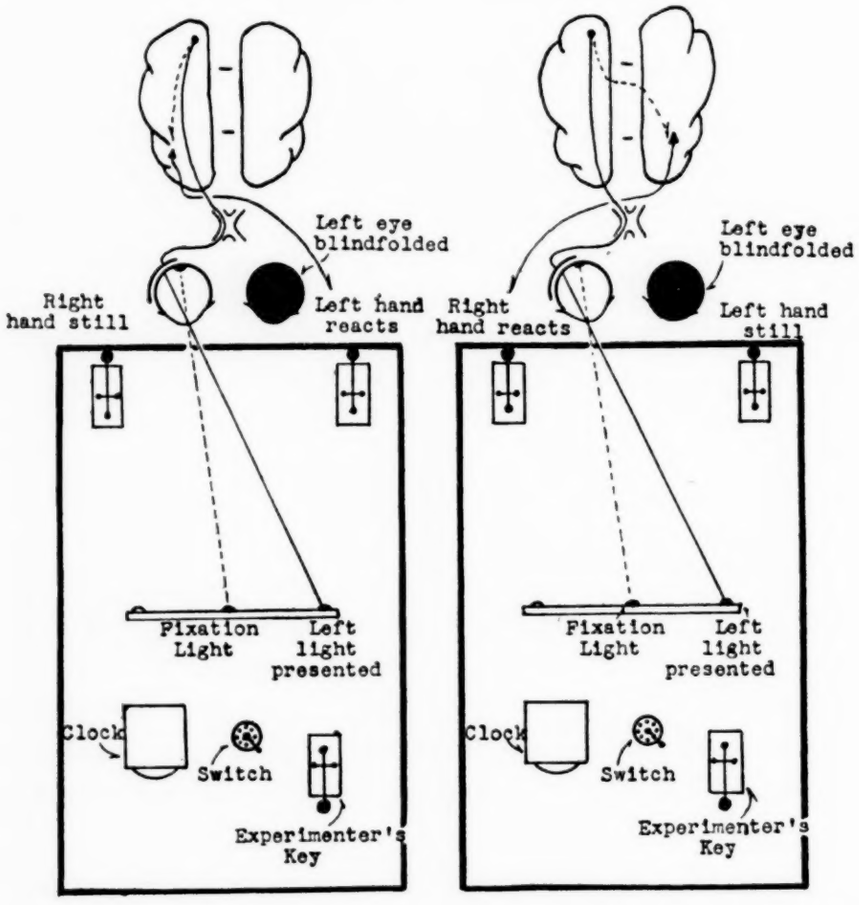


FIG. 1. The difference between two types of crossed and uncrossed visual reactions

Uncrossed Reaction

Involving the left stimulus light, right temporal retina, right visual cortex, right motor cortex, and left hand.

Crossed Reaction

Involving the left stimulus light, right temporal retina, right visual cortex, left motor cortex, and right hand.

[2] Standard Electric Time Clock Company

[3] C. H. Stoelting Company

involved in the crossed and uncrossed reactions. Uncrossed reactions are defined as those involving the following relations: (A) left temporal retina, left hemisphere, and right hand, (B) left nalsal retina, right hemisphere, and left hand, (C) right temporal retina, right hemisphere and left hand, (D) right nasal retina, left hemisphere, and right hand. Crossed reactions are defined as involving the following relations: (A) left temporal retina, left hemisphere, and left hand, (B) left nasal retina, right hemisphere, and right hand, (C) right temporal retina, left hemisphere, and left hand. These definitions are based upon generally accepted theories of retinal projection upon the cortex, and upon the experimentally established fact that motor activities of the hand and arm are determined functionally by the motor centers of the opposite cerebral cortex.

In the set-up used, three small red lights were arranged horizontally about 30 cm. apart on a panel. The *S*, fitted with a blindfold over one eye, fixated the center light. He responded to one of the other two lights as it was presented by releasing his key. In making measures of uncrossed reactions, he was instructed to respond with his left hand when the left light appeared and with his right hand when the right light appeared. Right- and left-hand reactions for each eye were obtained under these conditions to give the four types of uncrossed responses as described above. Determinations of response time for crossed reactions were secured by instructing the *S* to respond with his left hand when the right light appeared and with his right hand when the left light appeared. Measures of response for the two hands for each eye give the four types of crossed reactions as described above.

III. *Subjects.*—The principal *S*s in this experiment were six individuals who were brought into Strong Memorial Hospital, Rochester, New York, for surgery in relation to grand mal convulsions. The extent to which the intercortical pathways were sectioned in these patients is described in notes of the neurosurgeon [4] which were taken at the time of the operation. These descriptions may be abstracted as follows.

Subject 1. (E. C.) Complete section of the corpus callosum.
Subject 3. (G. E.) Complete section of the corpus callosum, and one year later, section of the anterior commissure.
Subject 5. (F. R.) Complete section of the corpus callosum.
Subject 13. (F. P.) Section of the corpus callosum except for one cm. at the tip of the splenium.
Subject 16. (W. M.) Section of the corpus callosum except for a few fibers at the tip of the splenium. Left fornix cut.
Subject 19. (L. M.) Section of the corpus callosum from the anterior tip to the point where the fornix joins the body of the callosum. The fornix was sectioned bilaterally.

Fig. 2 presents diagrams illustrating the nature of the operation in Subjects 1, 3, 5, and 16 (top figure) and in Subject 19 (bottom figure).

No direct histological evidence can be presented to confirm the accuracy of the surgeon's estimate of the extent of operation in each case. Postmortem examination of one patient (Subject 18), whose death was a result of circumstances not directly related to the operative procedures, confirmed the reliability of the estimate in one instance. In this case it was estimated that the corpus callosum was sectioned except for three-fourths cm. of tissue to the tip of the splenium. Approximately one cm. of the splenium was left intact, as illustrated by the artist's drawing of the fixed brain (Fig. 3).

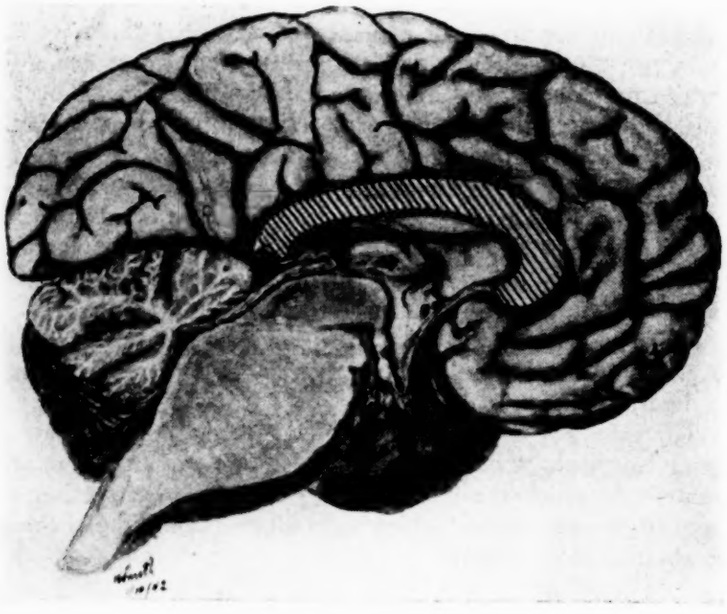
III. Theory and Hypotheses

The hypotheses which have guided the design of this experiment are as follows:

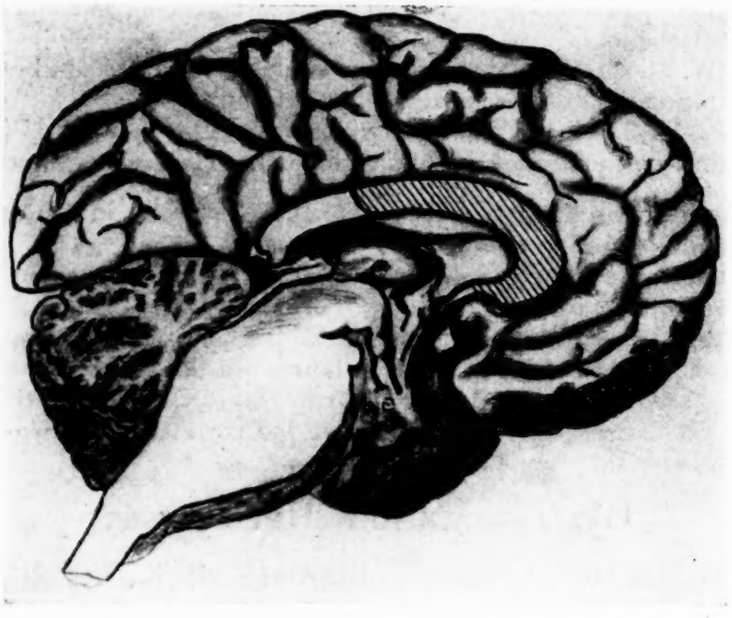
1. Functionally, the interhemispheral connections represent a significant part of the total neural association system of the hemispheres, and accordingly should have a role in determining particular neural integrations in verbal activities. Response time in verbal association should be increased after the intercortical neurones are sectioned if this hypothesis is correct.

[4] Dr. William P. Van Wagonen

2. Functionally, the neurones of the corpus callosum represent the main avenue of bilateral neural integration between the two cerebral hemispheres. If this hypothesis is correct, sensori-motor



A. The most extensive operation



B. The least extensive operation

FIG. 2. Diagrams illustrating the nature of the operations

reactions which involve crossed relations between the hemispheres should be more affected by sectioning these neurones than simple reactions or discriminative reactions which involve unilateral connections within the nervous system.

IV. Results

The results of this experiment are shown in Table I. The means of the differences between preoperative and postoperative tests are given in column 6, the *t*-ratios for these differences in column 7, and the level of confidence of the ratios in column 8. The percent difference between preoperative and postoperative tests is given in column 9.

The basic measurements as given in this table are represented by items 1, 2, 4, 5, 6 (simple reactions), 8, 9, 10, 11 (uncrossed visual discrimination reactions), 12, 13, 14, 15 (crossed visual discrimination reactions), 30, 31, and 32 (verbal association reactions). The remaining data represent means of combinations of these various basic measurements. A graphical summary of some of the results is given in Fig. 4.

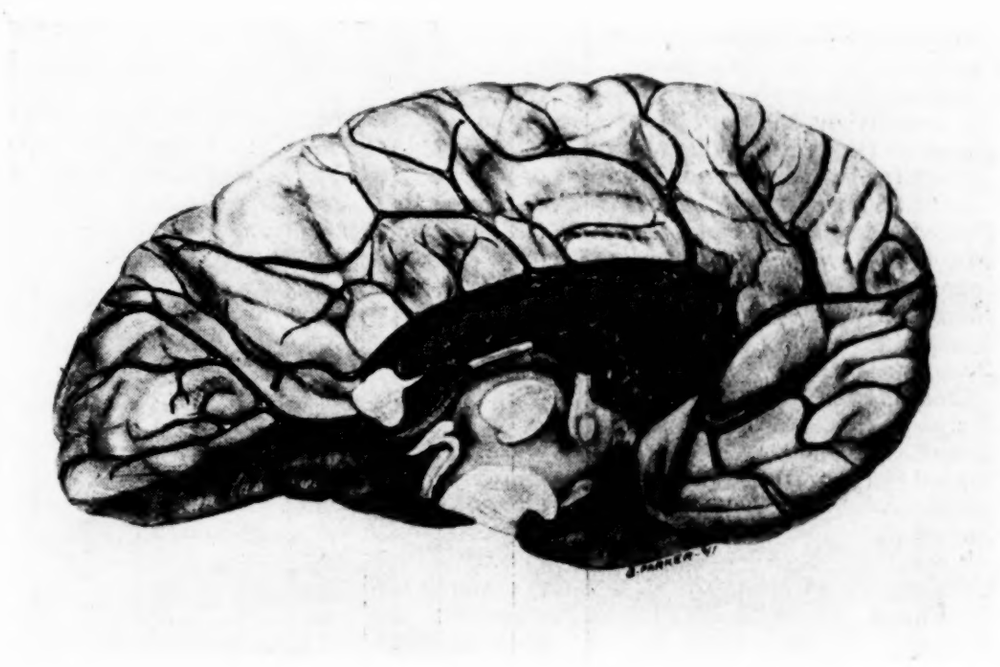


Fig. 3. The appearance of the fixed brain after section of the corpus callosum except for tip of the splenium

Some noteworthy information seems to be provided by these data.

Response time for all reactions tested is increased after the operation. Response time is increased more consistently for auditory reactions than for other simple reactions. The magnitude of change is greatest for the tactual reactions and least for auditory reactions.

Contrary to the main theoretical expectations, the significant effects of cutting the interhemispheral fibers lie in increasing remarkably the response time for simple direct reactions to stimuli.

TABLE I

CHANGE IN RESPONSE TIME AFTER OPERATION

Psychological Function	Preop.		Postop.		M_d	t	Level of Confidence	Percent Diff.
	M	σ	M	σ				
Simple Reactions								
1. Visual (right hand)	.20	.051	.28	.054	.08	2.01	.05	40
2. Visual (left hand)	.21	.049	.29	0.72	.08	2.43	*	39
3. Visual (both hands)	.20	.049	.28	.061	.08	2.75	.05	40
4. Tactual	.19	.049	.36	.149	.17	3.50	.05	89
5. Auditory (right hand)	.15	.039	.21	.039	.06	5.4	.01	40
6. Auditory (left hand)	.15	.036	.23	.065	.08	4.4	.01	53
7. Auditory (both hands)	.15	.037	.22	.046	.07	4.6	.01	48
Discrimination Reactions (Visual)								
8. Uncrossed (left eye-right hand)	.36	.066	.39	.059	.03	1.13	*	8
9. Uncrossed (left eye-left hand)	.39	.085	.46	.094	.06	2.25	*	15
10. Uncrossed (right eye–right hand)	.37	.089	.40	.079	.03	0.61	*	8
11. Uncrossed (right eye–left hand)	.36	.075	.46	.068	.10	3.34	.05	28
12. Crossed (right eye–left hand)	.40	.099	.48	.073	.08	2.20	*	20
13. Crossed (right eye–right hand)	.38	.074	.41	.068	.03	2.42	*	8
14. Crossed (left eye–left hand)	.41	.081	.47	.076	.06	2.84	.05	15
15. Crossed (left eye–right hand)	.39	.061	.42	.076	.03	1.08	*	8
16. Uncrossed (left eye)	.38	.071	.42	.062	.04	1.85	*	11
17. Uncrossed (right eye)	.37	.081	.43	.068	.06	1.57	*	16
18. Crossed (left eye)	.40	.070	.45	.071	.05	1.97	*	13
19. Crossed (right eye)	.39	.088	.44	.061	.05	1.82	*	13
20. Uncrossed (right hand)	.37	.073	.39	.073	.02	0.48	*	5
21. Uncrossed (left hand)	.38	.084	.46	.082	.08	4.63	.01	21
22. Crossed (right hand)	.38	.066	.41	.071	.03	0.69	*	8
23. Crossed (left hand)	.40	.084	.47	.073	.07	2.71	*	18
24. Uncrossed	.37	.076	.43	.066	.06	1.88	*	16
25. Crossed	.39	.076	.45	.067	.06	2.17	*	15
26. Left eye	.39	.071	.44	.065	.05	2.38	*	13
27. Right eye	.37	.069	.44	.064	.07	1.94	*	19
28. Right hand	.37	.068	.40	.069	.03	0.76	*	8
29. Left hand	.39	.084	.47	.073	.08	2.65	*	20
Verbal Associations								
30. Free-word	1.74	.293	1.83	.515	.09	0.76	*	5
31. Opposites	1.27	.364	1.48	.665	.21	0.81	*	17
32. Part-whole	1.85	.523	2.16	.461	.31	2.10	*	17
General								
33. Simple reactions	.18	.042	.29	.078	.11	4.68	.01	61
34. Discriminative reactions	.38	.074	.44	.062	.06	1.85	*	16
35. Verbal association	1.62	.372	1.82	.507	.20	1.10	*	12

* Below an acceptable level of confidence

This effect is found for visual, tactual and auditory reactions, and with one exception for both hands in all of these reactions.

The absolute magnitude of change in visual discrimination reactions is never as large as that for any of the simple reactions. The

chances are favorable that real increases were found in only three types of reaction (items 11, 14, 21) among the many different forms of discriminative response studied.

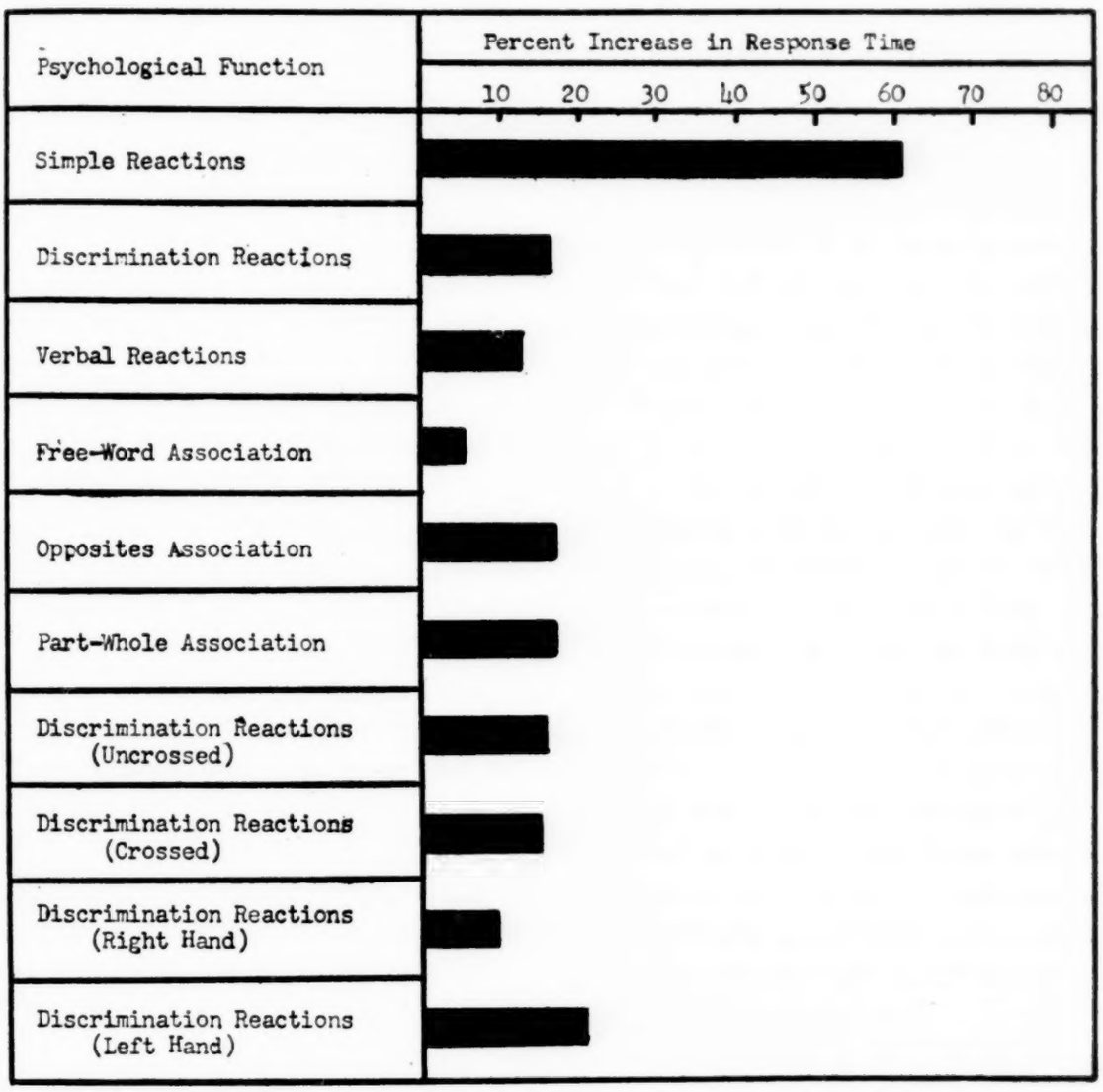


FIG. 4. The percent increase in response time in various psychological functions after section of the intercortical neurones of the corpus callosum

By referring to items 24 and 25 in Table I, and to the graph, it will be seen that sensori-motor responses involving presumed uncrossed and crossed hemispheric relations are not differentially affected by the sectioning of fibers between two sides of the cerebral cortex. The absolute change in these two types of response is not statistically significant.

In a series of control observations on normal Ss, the response time for uncrossed reactions was found to be significantly less than for crossed reactions ($N = 20$, $M_d = .05$ sec., $t = 8.15$). A similar, but statistically unreliable, difference between these two types of response is found preoperatively and postoperatively for the Ss in

this study. Evidently, cutting the fibers of the corpus callosum does not disturb in any noteworthy way the normal time relations which exist between these two types of response.

Among the discriminative reactions, significant postoperative increase in response time is found for uncrossed-right-eye-left-hand reactions, for crossed-left-eye-left-hand responses, and for all uncrossed left-hand responses. The changes in all crossed reactions involving the left hand also approach an acceptable level of confidence (item 23). The particular effect found with these reactions is interpreted as a handedness disturbance and not as specific motor defect of the centers for left-hand reactions, inasmuch as differences in the effect of the operation upon the response time for the two hands in the case of simple visual reactions is not apparent (items 5 and 6). For simple visual reactions, the change in response time for each hand is the same, but the consistency of this change is greater for the right hand.

The design of the experiment permits direct comparison of the effect of the operation upon discriminative reactions involving each eye and each hand (items 26, 27, 28, 29). Left-eye reactions are modified more consistently than right-eye reactions and to a slightly greater extent. As noted above, the increase for left-hand reactions is considerably greater than for right-hand reactions. The change in left-hand reactions approaches a favorable level of confidence.

Complete study of the reliability of measures of reaction time in the *Ss* used could not be made because of the circumstances of the experiment. However, retests were made after about one month on four *Ss*, two preoperatively and two postoperatively. The differences between the results of the two tests for the four *Ss* are shown in Table II. The results show that, although these individuals are quite variable in the time of their reactions, the magnitude of variation either preoperatively or postoperatively is not sufficiently large to account for the trend of results obtained in the main part of the experiment.

The analyses in this experiment have been made on a statistical basis and do not pertain to specific *Ss*. The *Ss* varied in regard to the magnitude of the operation and in regard to particular nerve bands sectioned. Examination of results obtained on each *S* discloses no noteworthy figures which would give cause to draw additional conclusions based on individual data. The only fact to be derived from these individual data is that the individuals with less extensive lesions showed generally as great an increase in response time as those with the more extensive lesions. The *S* with a lesion of the anterior commissure showed no critical variations in comparison with other *Ss*.

TABLE II

CONSISTENCY OF THE MEASURES OF RESPONSE TIME PREOPERATIVELY AND POSTOPERATIVELY

Psychological Function	Subject 5 Preop.		Subject 16 Preop.		Subject 1 Postop.		Subject 3 Postop.	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Visual Reactions	.16	.16	.20	.17	.25	.23	.33	.28
Tactual Reactions	.16	.16	.23	.18	.34	.32	.32	.27
Auditory Reactions	.13	.12	.17	.13	.22	.19	.26	.22
Crossed Visual Reactions	.31	.32	.40	.34	.48	.46	.53	.47
Uncrossed Visual Reactions	.29	.29	.36	.32	.53	.57	.48	.49
Free-Word Association	1.67	1.29	1.35	1.13	—	—	1.70	1.51
Opposites Association	.83	.76	.93	.83	—	—	1.58	1.11
Part-Whole Association	1.23	1.32	1.52	1.41	—	—	1.82	1.76

V. DISCUSSION

The results of this experiment appear to be theoretically significant for the following reasons.

The results on the different types of reactions observed, especially those secured on simple response time, account for the general appearance of inertia and lack of spontaneity which persists in patients with extensive lesions of the pathways connecting the two cerebral cortices. In fact, this radical increase in response time for simple reactions appears to be the only psychological function disturbed significantly by surgical section of the cerebral commissures among many different perceptual, motor, intellectual and sidedness activities which have been studied.

The observed increase in simple reaction time may prove that the neural association system of the cerebral cortex, of which the neurones of the corpus callosum form a major part, has a significant role in the dynamic regulation of motor adjustments specifically mediated by cortical and subcortical centers.

The results on discriminative reactions, which presumably involve crossed and uncrossed sensori-motor and hemispheric relations, prove it unlikely that the bilateral neural relations deemed basic for the crossed responses are determined by impulse channels at the cortical level through the intercortical neurones. These results are in general agreement with data already published concerning similar bilateral neural relations underlying visual perception (1). Apparently, subcortical centers or unknown functional activities in the cortex accomplish these bilateral activities of the visual system.

The observations made on verbal association tend to preclude acceptance of prevalent beliefs that mental reactions of this order in man may be determined by specific association pathways of the brain or by dominant and subordinant hemispheric relations. Inasmuch as the interhemispheral fibers of the corpus callosum form so prominent a part of the cortical association system, it seems likely that these neurones would form a number of specific channels of verbal association, if the cortex by nature functioned in terms of localized associative pathways.

It appears unreasonable to assume that associative nerve bands between the hemispheres other than those involved in the operations described are concerned primarily in the mediation of functions dealt with in this experiment.

Very generally, this experiment has provided very favorable circumstances for testing the application of the principles of cortical localization and specificity and that of functional configuration and organization within the cortex in describing the physiological basis of sensori-motor integration and verbal association in man. The results favor the second principle stated, which has already been demonstrated to apply to learning of sensori-motor habits in rodents (**2**). Results tend to show that lower levels of the nervous system must form in large part the means for joint neural activity of the two cerebral cortices or that, in a very similar way, unitary dynamic organization of the brain underlies the complex stages of integration between sensory stimulation and motor response.

(Manuscript received October 1, 1946)

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THE RELATION OF SECONDARY REWARD TO GRADIENTS OF REINFORCEMENT[1]

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Introduction and Statement of the Problem

Any systematic, quantitative theory of learning must be based on empirically determined laws between basic variables. One of these fundamental laws is the relation between the rate of learning a stimulus-response event and the time interval between its occurrence and reinforcement. The present investigation is concerned with the study of this functional relationship in an experimental situation in which an attempt has been made to minimize the role of secondary reinforcement.

The most precisely formulated hypothesis of the effect of delayed reward on learning is that given by Hull (**5**, p. 145). He states the hypothesis as follows:

> (1) The maximum habit strength (m') attainable with a given amount and quality of reinforcement closely approximates a negative growth function of the time (t) separating the reactions from the reinforcing state of affairs; (2) the asymptote or limit of fall of this gradient is zero; and (3) the more favorable the condition for the action of secondary reinforcement, the slower will be the rate of fall, so that this limit may not be approximated until after considerable periods of delay, though for many conditions less favorable for secondary reinforcement it may be reached in a period of from 30 to 60 seconds.

This formulation differs from Hull's earlier treatment in several respects, the most important of which is that it recognizes the *goal gradient* as a kind of second order phenomenon which results from the joint operation of two basic principles: (1) a more basic, primary *gradient of reinforcement* and (2) secondary reinforcement.

The experimental basis for this modification of Hull's theorizing was the finding by Perin of a much less extended temporal gradient of reinforcement than had been obtained in earlier studies. Perin's results (**7**, **8**) suggested that the delay gradient did not extend beyond 60 sec. and possibly was as short as 30 sec., whereas the studies of Wolfe (**11**) and Hamilton (**3**) had shown that rewards delayed as long as 5, 10 and even 20 min. were effective in producing learning.

[1] This article is a slightly modified version of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Psychology of the Graduate College of the State University of Iowa. The writer wishes to express his appreciation for the valuable advice and assistance of Professor Kenneth W. Spence throughout this work.

[2] Now at Kent State University

The discrepancy between these experimental findings, the obtaining of long gradients in some studies and short gradients in others, Hull attributed to the varying extent to which conditions favorable for secondary reinforcement were operative in the learning situation. According to the principle of secondary reinforcement, any stimulus which is closely and consistently associated with a reinforcing state of affairs will itself acquire the power of secondary reinforcement. Applying this to the delayed reward learning situation, the stimulus cues in the delay compartment acquire secondary reinforcing properties because of their spatial and temporal proximity to the food compartment and thus serve as *immediate* secondary rewards for the response being learned.

In the case of the learning of an extended series of responses with food reward being given only at the completion of the final response, Hull conceives of the reward as having from the beginning of learning a limited gradient of reinforcement (30–60 sec.) which is gradually extended as stimulus cues within the range of this gradient themselves acquire secondary reinforcing properties. That is, once the stimulus cues preceding the food reward become secondary reinforcing agents, they are assumed to operate according to the same primitive gradient of reinforcement, thus extending the secondary reinforcing powers to still more antecedent stimulus events. Hull identifies his original *goal gradient* with the complex gradient resulting from the summation of these many overlapping, short gradients. The latter, short gradient is called by Hull the '*gradient of reinforcement*' and is referred to as basic or primary. In most learning situations secondary reinforcement is operative and the obtained gradient is the *goal gradient.* Perin obtained a much shorter delay-of-reinforcement gradient than other experimenters, Hull believes, because he succeeded in eliminating, or at least greatly reducing, the operation of secondary reinforcement. Unfortunately, Perin's studies do not provide too clear a picture as to why secondary reinforcement was less effective in his learning situation. The chief difference between Perin's experiment and other studies of delay of reward was that in the former the learned response occurred in the goal box itself, whereas in the others it preceded the goal box and even the delay compartment. This fact would suggest that *all* responses made by Perin's *S*s were followed by more or less the *same* secondary reinforcing cues, those in the goal box, and hence there was relatively little differential reinforcement of any particular act. In the case of the simple T-maze used by Wolfe the correct response led to different cues from those following the incorrect turn and, furthermore, these two sets of cues obtained differential (secondary) reinforcing properties.

Whatever the explanation of Perin's data, the hypothesis that the extent of the delay of reinforcement gradient is a function of the degree to which secondary reinforcement is operative seemed worthy of further investigation. The present study undertook to investigate this hypothesis in a simple T-maze situation similar to that employed by Wolfe. In order to eliminate or minimize the effectiveness of the secondary reinforcing cues normally provided by the delay compartment on the correct arm of the maze, the delay compartments were interchanged from trial to trial in a random manner. Furthermore, the maze was covered by opal flashed glass and its position was rotated 180 degrees each day, thus effectively eliminating any differential cues from outside the maze. In this manner all *differential* cues following the choice behavior, except internal cues provided by the *S*'s own responses (i.e., proprioceptive), were eliminated. There was thus no possibility of *differential* secondary reinforcement from cues in the external environment of the *S*s. The learning of five groups of *S*s with different delays of food reward (0, 5, 15, 45 and 120 sec.) was studied under these conditions. Finally, in order to ascertain directly the effect of eliminating these differential secondary cues, a control group with a food reinforcement delay of 45 sec. was also run. In the case of this group the same delay compartment always preceded the goal box even though the maze as a whole was rotated. Furthermore, the delay compartments were made as unlike as possible so as to minimize the effects of generalization. Comparison of the learning of this group with the comparable delay group run under the experimental conditions would give some indication as to whether secondary reinforcement played any role in delayed reward learning.

Apparatus

The apparatus used was a simple T-maze consisting of five parts: a combined starting box, stem and choice section, two delay boxes, and two goal or end boxes. A ground plan of the maze is shown in Fig. 1.

The entire maze was enclosed, the sides and other wooden portions being made of white pine painted grey unless otherwise specified. The starting box and first 24 in. of the stem were made entirely of wood. The remaining 12 in. of the stem and the 10-in. arms attached to it had a floor and roof of opal flashed glass. The 18-in. delay boxes had similar glass portions. All alleys were 4.5 in. high and 4 in. wide (inside measurement) except the last 8 in. of the stem, which was 2.75 in. wide. The end boxes were 12 in. long, 6.5 in. wide, and 5.5 in. high. They had opal glass roofs and wooden sides. The positive goal box was painted white and its beaverboard floor was covered with hardware cloth; the negative end box was black and had a beaverboard floor. Both contained wooden food cups. A special delay box similar to the regular one in its spatial dimensions, but with vertical black and white stripes painted on the sides and with a strip of hardware cloth ½ in. above the entire glass flooring, was used with the control group.

Opal flashed glass doors, 4½ × 6 in., were located at the entrance to each of the two arms of the T, at the entrance of each of the delay boxes, and at the exit of the starting box. Wooden doors, painted grey, controlled entrances into the end or goal boxes from the delay compartments. Grey curtains were placed in each alley eight in. from the choice point.

The maze was lighted from below by means of 7.5-watt bulbs installed on an attached base 12 in. beneath the maze floor. There were three bulbs under each delay box and four under the stem unit, so arranged as to give uniform lighting within the maze and allow the *E* to follow the progress of the rat by the shadow produced on the roof of the apparatus. One 7.5-watt bulb was suspended six in. over the end of each end box.

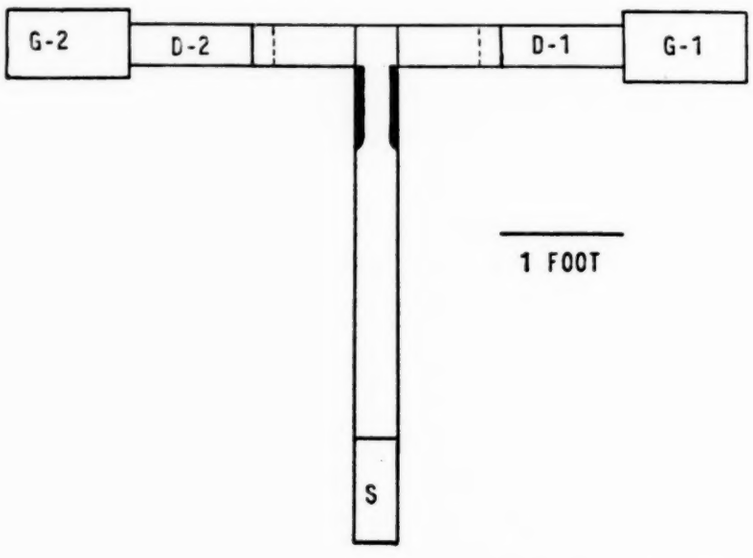

FIG. 1. Floor plan of the maze. S—starting box; D-1, D-2—delay boxes; G-1, G-2—end boxes

In the preliminary training a 52-in. enclosed runway was used. The first 28 in. of this were constructed entirely of wood, while the final 24 in. had a roof and floor of opal glass. The lighting was similar to that in the T-maze. There was a flashed glass door at the goal box end of the runway, and a grey curtain was placed eight in. in front of it.

SUBJECTS

The *S*s were 124 rats from the colony maintained by the Department of Psychology of the State University of Iowa. Their ages ranged approximately from 80 to 170 days at the beginning of the experiment. The group consisted of 61 males and 58 females, 16 hooded and 103 albino animals. Five *S*s were discarded during the course of the investigation, four due to mistakes on the part of the *E* and one on account of sickness.

PROCEDURE

Preliminary training.—All *S*s were put on a regular 24-hour feeding schedule for at least one week before the beginning of the preliminary training. During this period and throughout the experiment the daily ration was eight gm. of Purina Dog Chow.

There were seven days of preliminary training. On the first three days the *S*s received four runs in the straight runway to the positive goal box and one pellet (.25 gm.) of their regular food. On the following four days they received four runs on this runway each day, half of which led into the white goal box containing food and half of which led to the black end box which was without food. This training was intended to build up secondary reinforcement properties in the white box and extinguish any such properties in the black box which might have been produced by generalization from the positive end box.

As in the learning series, the *S*s were run in squads of from five to eight, each squad being made up exclusively of either males or females. The daily ration was given in the individual feeding cages after the last run of the day. This procedure provided for a 22- to 23-hour food deprivation period.

Learning series.—The animals in the experimental groups were roughly equated for age, sex, strain (hooded or albino), and litter. Individual *S*s within these groups were randomly assigned to the five different delay groups. Each squad contained one or two animals in each group, so that variables such as time of day were also controlled.

Experimental treatment of the groups differed only with respect to the length of time the *S*s were retained in the delay boxes. Delays of 0, 5, 15, 45, and 120 sec. were employed. For the zero delay group, all doors were open until the rats had passed under them. For the remaining groups, the doors next to the goal boxes were closed and were opened only after a *S* had been in the delay box for the appropriate period of delay. All doors were closed as soon as the rats had passed through them and no correction was allowed. All *S*s were removed from the positive goal box as soon as they had consumed the pellet and from the negative end box after 15 sec. In the few cases in which *S*s refused to enter the negative end box within three min. of the opening of the door, they were removed from the delay box by the *E*.

For half of the *S*s the right side of the maze was positive or reinforced, and for half the left side was made positive. The turn which was reinforced for any given animal was arbitrarily selected before the *S*'s first run. The white goal box was always on the positive side and the black always on the negative.

The delay boxes were interchanged in an irregular manner, so that each was on the correct side in half of the trials and on the incorrect side for the other half of the trials. Furthermore, the starting box, stem and choice point section of the maze were rotated 180 degrees each day, so that the orientation of the apparatus in the room was reversed from one day to the next. Thus there was no possibility for a constant stimulus from outside the maze to provide an orientation cue which might attain differential reward properties. Likewise, cues from within each delay compartment followed the correct and incorrect responses equally often. Not only did these cues follow the two alternative responses indiscriminately, but they were also, in turn, followed equally often (50 percent of the time) by the positive goal box. This procedure thus effectively eliminated any differential secondary reinforcement by means of stimulus cues from outside the maze or inside the delay compartments.

The control group of *S*s, numbering 20 animals, was run with a 45-sec. delay of food reward. The essential differences between it and the corresponding experimental group were that the delay compartments were kept in a constant position relative to the choice point and that they were made quite different from one another. One delay box was the same as that used with the experimental groups, while the second had hardware cloth covering the floor and the side walls were painted with alternate white and black stripes. For half of the control *S*s this special delay box always preceded the positive goal box, while for the other half the standard grey delay compartment always preceded the goal box. Under these conditions, not only did the delay boxes following the two alternative responses provide different stimulus cues, but also one set of these cues was consistently followed by reward and the other was not. The same procedure of rotating the maze on alternate days was employed, which limited the differential external secondary cues to those within the delay compartments, and kept the complex of stimuli at the choice point the same for both groups. Thus, in the case of every animal in this group the delay box on the correct side could gain differential secondary reinforcing power.

All *S*s in the experiment received four runs a day with intervals between trials of 15 to 30 min. All *S*s were run until they had reached a criterion of five days with all runs to the correct side, or in the case of the 0, 5 and 15 sec. groups until they had received 40 reinforcements plus four trials and in the case of the 45 and 120 sec. groups until they had received 60 reinforcements plus four trials. For purposes of group data it was assumed that after five successive days with all runs to the correct side, all subsequent runs would be to this side. There were 19 rats in the zero delay group and 20 in each of the others, a total of 119 including the control group.

Results and Discussion

1. *Comparison of learning in the experimental and control 45-sec. delay of reward groups.*—According to Hull's most recent formulation of the goal gradient hypothesis, as may be recalled from the discussion in our introductory section, the height and extent of the delay of reinforcement gradient is assumed to be a function of the degree to

which secondary reinforcement is operative in the experimental situation. Beyond the limits of the primary or basic *gradient of reinforcement*, which possibly is as brief as 30 sec., the effectiveness of any particular amount of delayed reward in producing learning will depend upon the degree to which conditions are favorable for the development of secondary reinforcement. A test of this hypothesis is provided by comparing the learning of the two different groups of *S*s, experimental and control, in which the food reward was delayed for 45 sec. The finding of a faster rate of learning in the control group would be evidence in support of this hypothesis for, it will be recalled, every effort was made to arrange conditions favorable for differential secondary reinforcement in this group and unfavorable in the case of the experimental group.

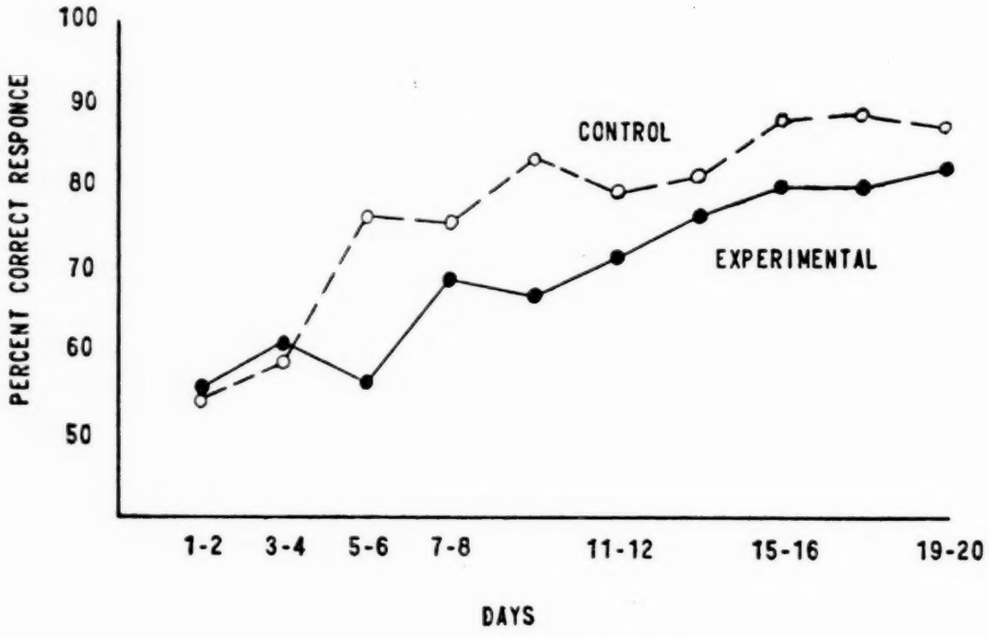

FIG. 2. Learning curves for the 45-sec. delay groups, experimental and control, as based on percentage of correct responses in successive two-day periods

Fig. 2 presents the data on learning for these two groups in terms of the percentage of correct responses occurring on successive pairs of days (eight trials). An examination of the learning curves shows that the hypothesis is supported. Whereas the control group started out slightly below the level of performance of the experimental group, after the fourth day its curve rose more rapidly and continued consistently above that of the experimental group.[3] Table I, which

[3] It is interesting to note, however, that our data suggest that the effects of stimuli during the delay which may acquire properties of secondary reinforcement are not immediately apparent from the *S*'s behavior. If, as Hull suggests, anticipatory goal reactions are the basic mechanism underlying secondary reinforcement, this finding may indicate that such anticipatory responses must attain a reaction tendency surpassing their reaction threshold before they can take place.

gives the mean and standard deviation of the number of correct responses made by each group, shows that the overall learning scores are significantly different. The mean difference of correct responses provides a t of 3.15 which is significant beyond the one percent level of confidence.

TABLE I

COMPARISON OF 45-SEC. GROUPS, EXPERIMENTAL AND CONTROL

Group	N	Mean	σM	Difference	t
Experimental	20	55.95	(1.35)		
Control	20	61.90	(1.31)	5.95	3.15

This result thus tends to lend support to the conception that the rate of learning in a delayed reward situation depends upon the degree of control of differential secondary reinforcement. The elimination or reduction of such reinforcement provided by stimulus cues in the external environment apparently leads to a slower rate of learning.

2. *Comparison of Learning of the Experimental Groups.*—The primary learning data for the various delay (experimental) groups are presented in two different ways.

Fig. 3 shows curves of learning in terms of the percentage of correct responses made by a group on successive two-day periods (eight trials). It is readily apparent from an examination of this figure that the rate of learning is definitely a function of the extent

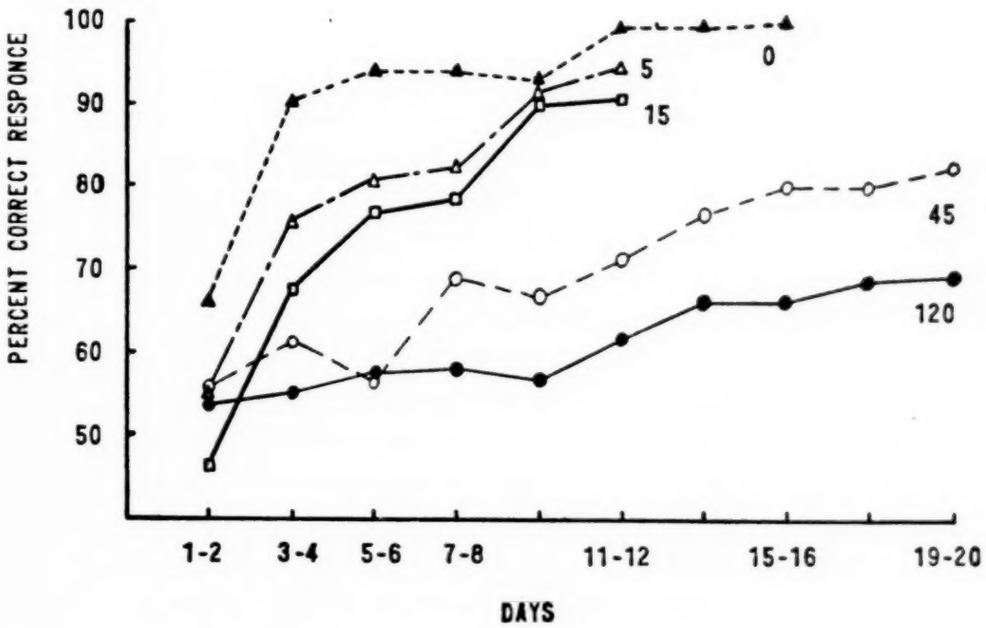

FIG. 3. Learning curves for the experimental groups with 0, 5, 15, 45, and 120 sec. delay in terms of percent correct responses for successive two day periods

to which the reward is delayed. Thus when the zero-delay group had reached the 100 percent level of performance, the longest delay group (120 sec.) was responding correctly only 62 percent of the time, while the intermediate delay groups fell in order between these values.

Since there was no overlap between the total number of errors made by *Ss* in the zero-delay group (all of whom reached the criterion of no errors on five successive days) and the number made by *Ss* in the 120-sec. group, no test of significance is needed to demonstrate that the superior performance with zero delay is not due entirely to chance. Furthermore, the rank order relationship between time of delay and percent correct responses for the five groups is perfect after the first pair of days except for a slight reversal in the position of the points for the 45- and 120-sec. groups on days 5–6. Thus it seems safe to conclude that the superiority of any group over any other group with a longer time of delay is not due to chance factors. It is also apparent that the two shortest delay groups, like the zero delay group, would very likely have reached the 100 percent level of performance if their training had been continued further. It is more difficult to determine whether this would be the case with the two longest delay groups. There certainly is little to suggest that either group's performance was approaching an asymptote.

The second method of presenting the learning data is shown in Fig. 4. It differs somewhat from the more conventional methods of representing such data, particularly with respect to the measure employed as an index of learning. Suggested by Hull (**5**), this measure is derived from the percentage of correct responses made on a block of trials in a manner analagous to the familiar method employed in translating percentile scores into standard scores on the basis of the normal probability distribution. The assumption underlying the derivation is that the excitatory (habit) [4] strengths of the two competing responses fluctuate from moment to moment according to a normal or chance distributed oscillatory function. This necessarily implies that the differences between these competing response tendencies at any moment also oscillate according to a normal distribution. When the difference between the strengths of the two responses is zero, this oscillating factor tends to give about equal (50 percent) choices of the two alternative responses. As the difference between them develops with the reinforcement of one and nonreinforcement of the other, the probability of occurrence of the stronger increases until the difference becomes greater than the most extreme oscillation and the reinforced response occurs thereafter 100 percent of the time. By means of tables of the normal probability

[4] Since inhibitory tendencies are assumed to be held constant in the present situation, habit strength and excitatory strength are linearly related and the terms may be interchanged.

function it is possible to convert any percent of occurrence of one of the responses into an amount of difference value. In effect this procedure translates a percent of choice value into a kind of standard score which represents along a scale the difference in the excitatory (habit) strengths of the two competing responses. If we now assume that excitatory (habit) strengths of the incorrect responses decrease, if at all, in a uniform manner in the different experimental

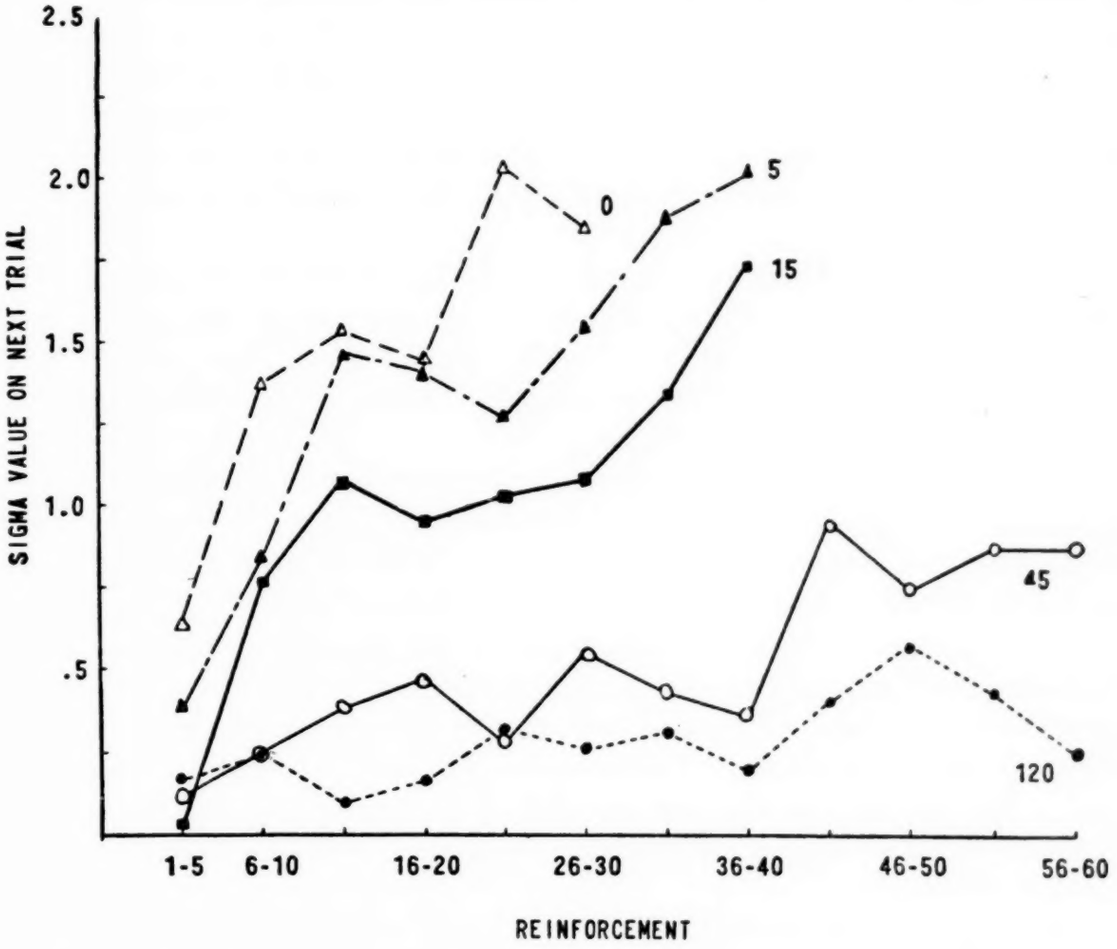

FIG. 4. Learning curves for the five experimental groups as based upon sigma values on the trials immediately following each of five successive reinforcements

groups, this measure may be taken as reflecting fairly closely the development or growth of the excitatory (habit) strengths of the correct response in the different experimental groups.[5]

The unit on the abscissa in this graph is the number of previous *reinforcements*. The reason for using these units rather than trials

[5] So far as the writer is aware, there are no experimental data bearing on the question as to whether variations of the time in the delay box on the incorrect side make for any difference in learning in the T-maze. There is evidence to show that variation of the relative number of non-reinforcements (e.g., doubling them) has no effect on learning (1, 10). This would suggest that the major factor in developing a difference in the strength of the competing responses is the building up of the strength of the positive response with reinforcement.

or days is that if these latter units were used, the number of previous reinforcements would not be constant for different groups, since the fast learning groups would have received a greater number of reinforcements preceding any given day after significant learning had taken place. Thus, trial and previous reinforcement units cannot be equated, and since reinforcements rather than trials are the units in terms of which Hull's theory is formulated they are preferred for our present purposes. In order to smooth the curves, these have been grouped into blocks of five reinforcements. Thus, the first point on each curve is determined by first ascertaining the percent of correct responses made on the trials immediately following the first, second, third, fourth, and fifth reinforcements and then looking up the appropriate value corresponding to this probability score in the normal probability table.

The learning curves obtained by means of these procedures present a number of interesting aspects. First of all, on the assumption that these curves do reflect primarily the development of the habit or excitatory strength of the reinforced response, it will be seen that the upper three curves tend definitely to be negatively accelerated and could be fitted fairly satisfactorily by the type of exponential function that Hull postulates. In other words these curves are in line with Hull's assumption that habit (excitatory) strength is an exponential function of the number of reinforcements.

It will be observed, however, that the learning curves for the longest delay groups would appear to be fitted better by a straight line than a negatively accelerated curve while that for the next shortest delay group would also appear to approximate a linear function. Before explaining this possible departure from an exponential function, it is necessary to examine certain aspects of Hull's theory in greater detail.

Hull apparently assumes (**5**, 146 f.) that curves of the development of habit (excitatory) strength will be exponential no matter what the extent of delay of reward. However, this is not consistent with his treatment of the nature of the goal gradient as dependent on the short gradient of reinforcement and effects of secondary reinforcement. If the delay exceeds the limit of this primary gradient of reinforcement, there will be no increase in the strength of the reaction tendency following a response until stimuli following the response by an interval less than that involved in the primary gradient have acquired secondary reinforcing properties. In such cases we would be led to expect positive acceleration in the habit growth curve in the early stages of learning. With delays slightly less than the interval covered by the primary gradient of reinforcement we might expect the learning curve to approximate a straight line, since the decrease

in the increment of habit on successive trials resulting from primary reinforcement would be counteracted by the increasing increments due to the development of secondary reinforcement.

The further possibility exists, of course, that the curves for the two longest delay groups are exponential in form. In fact, this interpretation would be plausible if their maxima or asymptotes were relatively low, with the result that the change in the successive increments would be very small. The variability of the curves certainly does not permit the rejection of this interpretation. It is unfortunate that a longer period of training was not given to these groups in order to establish definitely their limits of learning.

3. *Delay of reinforcement gradient.*—In his reformulation of the goal gradient hypothesis Hull postulates that it is the maximum habit strength attainable that is an exponential function of the delay of reward. In his use of this hypothesis to account for various complex maze phenomena, e.g., learning to choose the shorter of two paths to a goal, he further assumes that the habit growth to these maxima will also be exponential. It necessarily follows from this that the amount of learning at any point in the training period will vary according to an exponential function with the amount of delay of the reward.[6]

The present study does not permit a plotting of the maxima, but Fig. 5 gives data at two different stages of practice. The ordinate in this graph denotes the level of performance in sigma values, while the delay variable is represented in seconds on the abscissa. The experimental values on the upper curve are from the practice period represented by 26 to 35 reinforcements, those on the lower curve for the period 6 to 15 reinforcements. The smooth curves fitted to the data are exponential functions, the equations of which are:

$$S = 1.89e^{-.0485T} + .285 \text{ (upper)},$$
$$S = 1.29e^{-.046T} + .165 \text{ (lower)}.$$

It is readily apparent that the data are fitted very well by this type of function. However, the number of points limits the significance of the findings.[7]

[6] As has been pointed out above (Section 2 of the Results and Discussion), Hull's assumption that the learning curves for long delays are exponential is inconsistent with his treatment of the manner in which the goal gradient is assumed to develop from the summation of the overlapping short, primary gradients. It is probable, however, that the slight amount of departure involved would not produce a sufficient difference in the delay gradient to be detectable with the small number of observations in the present experimentation.

[7] For example, the present data do not provide a critical test of the issue as to whether the gradient is logarithmic or exponential. In his original formulation Hull used the logarithmic function. Later he rejected this on both logical and empirical grounds, and selected the exponential.

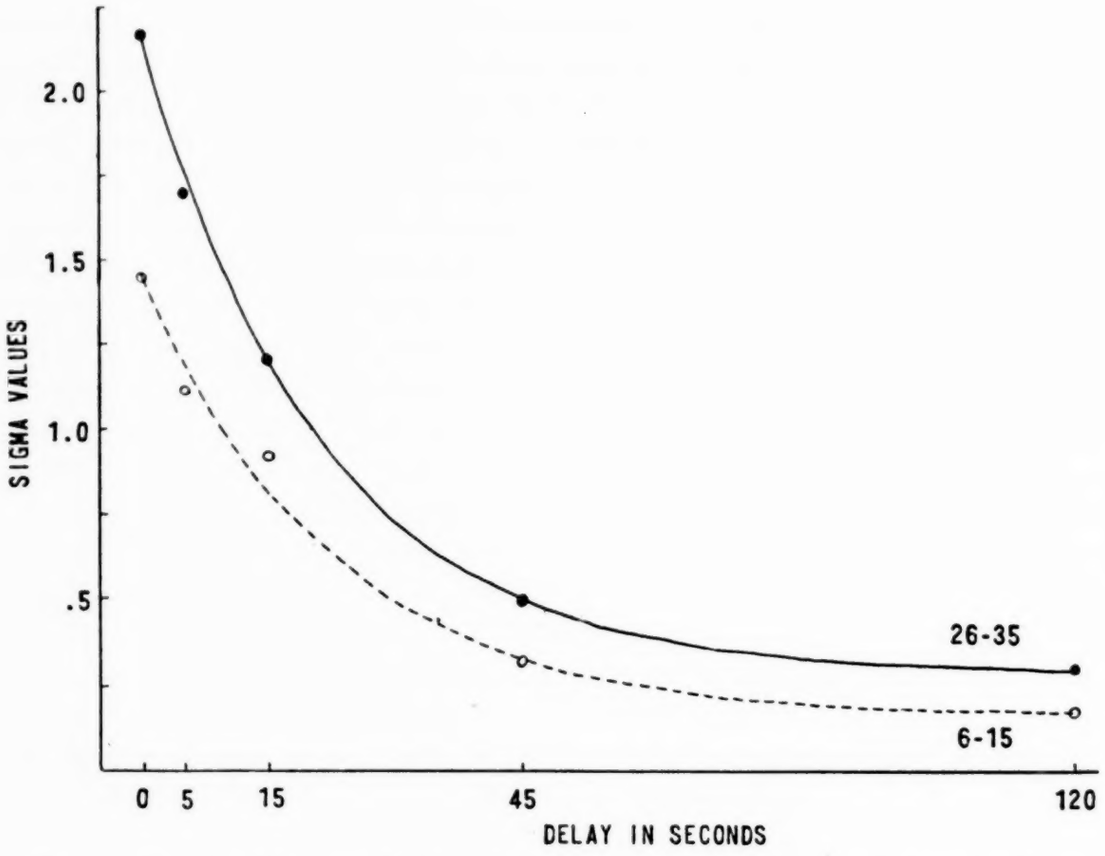

FIG. 5. Exponential curves fitted to the points obtained by plotting performance in terms of sigma values on the trials following reinforcements 6 to 15 and 26 to 35, and time of delay in sec. The empirical points obtained on trials following reinforcements 6 to 15 are indicated by open circles and those obtained on trials following reinforcements 26 to 35 by solid circles.

In order to provide a comparison of the delay gradient obtained in the present study with that found by Wolfe (**11**), Fig. 6 was prepared. The upper set of data (squares) in this figure are the learning scores for days 7, 8, 9 and 10 in Wolfe's study. These values, obtained in the same manner as the sigma values used in the present studies, were taken from Hull's discussion of Wolfe's data (**5**, p. 161). The exponential curve fitted to the data by Hull is as follows:

$$S = .835e^{-.066T} + .375.$$

The lower set of data (circles) are sigma scores determined from the percentage of correct responses made on days 1 to 12 in the present study. This set of learning scores was used because the level of correct responses at zero delay reward was approximately the same as that for Wolfe's data, and thus facilitated comparison between them. The equation [8] for this set of data is:

$$S = 1.03e^{-.048T} + .173.$$

[8] It is of interest to note that more or less the same value (.048 approximately) for the coefficient or parameter determining the rate of approach of the curve to its limit was found for the different curves of the present experiment.

It is apparent from this graph that the gradient found in the present study falls within the delay interval shown to a lower level than that of Wolfe. This finding is in accord with Hull's hypothesis that the level of the goal gradient will depend upon the conditions favorable for secondary reinforcement and the assumption that the present experimental procedure reduced differential secondary reinforcement by eliminating differential external cues following the critical response.

A further question which might be raised with respect to the learning in the present study is whether or not the gradient falls to

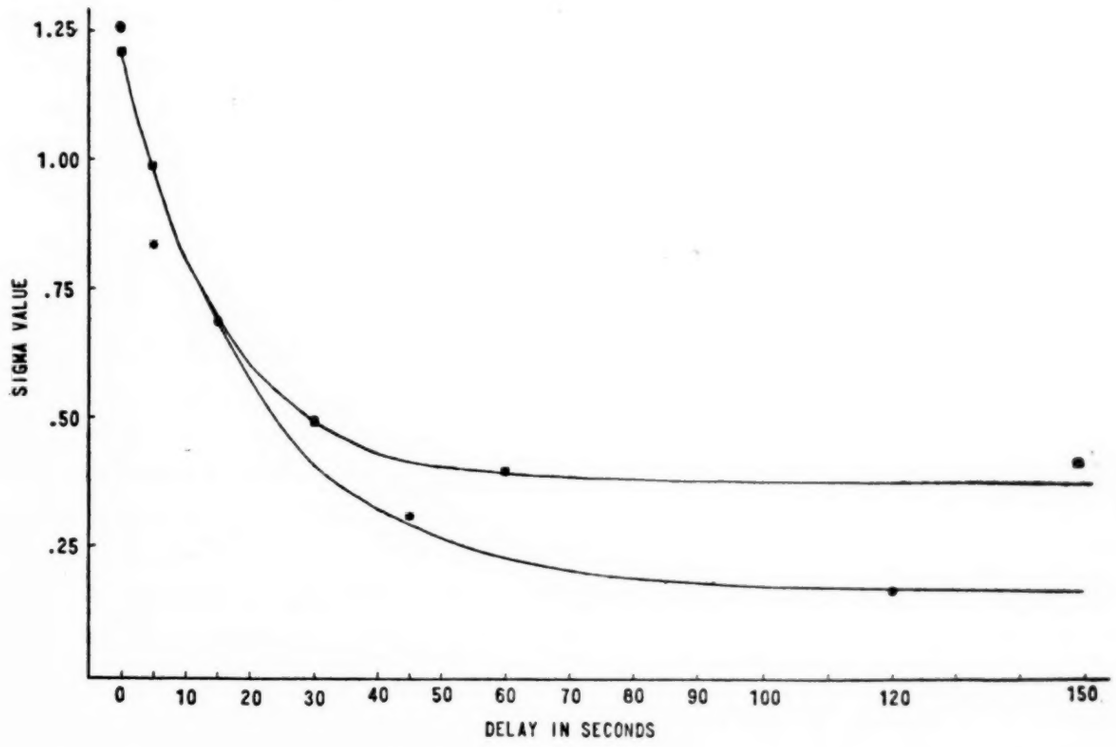

FIG. 6. Exponential curves fitted to points obtained by plotting sigma values for a block of trials against time of delay in sec. The upper curve is fitted to points (squares) obtained by Wolfe on trials 7, 8, 9 and 10, the lower to points (circles) obtained on days 1 to 12 in the present study.

zero before 120 sec., or, in other words, was there any learning at this delay? Examination of the curves for this group in Figs. 3 and 4 suggests that there was, for they show a fairly consistent upward trend towards a higher learning score. Two different methods of statistical analysis confirm this inference. The first involved a *t* test of the significance of the difference between the mean number of correct responses made by the group on the last four days of learning with the comparable score for the first four days. A *t* of 3.59 was obtained for the difference of 2.4 (11.1–8.7) which is significant at well beyond the one percent level of confidence for the appropriate

degrees of freedom. As a further check on this question, analysis of variance was used to test the hypothesis that the changes in the amount of training are not accompanied by changes in the mean number of responses correct on the successive two-day periods.[9] An F of 3.6 was obtained, which for 9 and 171 degrees of freedom is significant at the one percent level, thus permitting us to reject the hypothesis that the change was one that was likely to occur by chance (6).

4. *Theoretical interpretation.*—An important question which arises in connection with the delay gradient found in the present study is whether it is based on secondary reinforcement or is a kind of basic or primary gradient. The interpretation that it is a primary gradient would not seem to be in accord with the much shorter gradient obtained by Perin (7, 8). The fact that the latter found no learning when the food was delayed for 30 sec. suggests that a primary gradient, *if such exists*, does not extend as far as the gradient found in the present study.

On the other hand, if the gradient involves secondary reinforcement, what are the differential stimulus cues which provide for it? One very plausible possibility is that they are provided by the different proprioceptive cues which follow the left and right turning responses. Even though all the external cues were satisfactorily controlled in the present study, it is obvious that this proprioceptive source of stimulation necessarily provided a different pattern of cues for a certain period of time following the response. The consistent reception of food within this period would lead to the development of secondary reinforcing properties in the cues following the correct responses. The gradient of delay might possibly reflect the degree of differentiation in the proprioceptive stimulus patterns at various moments following the response. The conditions of the present experiment differed from the more usual reinforcement conditions, then, only in that they presumably eliminated all differential stimulation from the external environment. The lower asymptote of the gradients in the present study as compared with that found in Wolfe's study would be interpreted as due to the lesser differentiation of the stimulus patterns following the critical responses because of the equating of the external cues. The differential proprioceptive cues nevertheless still provided a good basis for differential secondary reinforcement.

Further evidence in support of this interpretation is provided by the experimental finding that when the reward and frustration are delayed as little as four seconds in discrimination learning, no learn-

[9] The S's scores were arranged in rows and the two-day periods in columns. The F was obtained from $\sigma_c^2/\sigma^2_{rxc}$.

ing takes place (**2, 9, 11**). As the cue stimulus aspects, e.g., white and black cards, are shifted from left to right, there are in this case no characteristic proprioceptive cues that precede the goal and hence could provide the basis for secondary reinforcement. This finding would suggest that all learning by delayed reward involves immediate secondary reinforcement by some type of differential cue, or in other words that there is no primary gradient of reinforcement.

Summary

1. Five groups of white rats with delays of reward of 0, 5, 15, 45, and 120 sec. were run in a simple T-maze under conditions which eliminated differential external stimulation in the delay chambers following correct and incorrect choice. A control group, which differed from the corresponding experimental group in that differential external stimuli were present during the delay period, was also run under the condition of 45 sec. delay.

2. Comparison of the results from the two 45-sec. groups, experimental and control, showed a statistically significant difference in the rate of learning in favor of the control group.

3. The results from the five experimental groups showed that the shorter the delay, the more rapid the rate of learning. A plot of the level of performance at any given point in the learning series as a function of the time of delay gave a negatively accelerated function which was fitted satisfactorily by an exponential curve.

4. The three short delay groups had a negatively accelerated rate of learning, while the incomplete learning curves for the two longer delay groups were approximately linear in form.

5. The results from this and other studies were interpreted as supporting Hull's hypothesis that the range of the goal gradient is extended and its rate of fall slowed up by the effects of secondary reinforcement. It was also suggested that the slope and extent of the gradient of reinforcement obtained in the present experiment is possibly dependent on the rate of change of the perseverative (kinesthetic) trace resulting from the response being learned.

(Manuscript received October 19, 1946)

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ACQUISITION OF MOTOR SKILL: II. ROTARY PURSUIT PERFORMANCE WITH CONTINUOUS PRACTICE BEFORE AND AFTER A SINGLE REST *

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INTRODUCTION

In a previous article (1), the author tentatively outlined a quantitative system for the analysis of motor performance curves. Pertinent literature was reviewed and certain postulates concerning the interrelationships of the factors proposed. It was pointed out that the appearance of certain of the more significant phenomena in motor learning is contingent upon the 'pacing' of practice early in the acquisition of a skill, e.g., rotary pursuit where the *S* is forced to work at a rate more rapid than he would choose for himself.

Under these conditions the post-rest performance curve will be characterized by a sharp initial rise, a relatively decremental section, and a resumption of improvement. These characteristics can be seen in Fig. 1, a schematic drawing. Following is a list and explanation of the variables shown in Fig. 1, certain of which will be used in the analysis of the experimental data to be reported.

A—represents the curve of performance if no rest had been introduced. In the following study, straight lines were fitted to the pre-rest performance curves by the method of average decrement.[1] Only in the case of the 8- and 17-min. pre-rest practice groups did there appear to be sufficient points on which to base individual equations for line *A*. Fig. 2 gives two mean pre-rest performance curves—one for the 98 *S*s in the 8-min. and one for the 98 *S*s in the 17-min. pre-rest practice group. A linear equation was fitted to each by the method of average decrement. These two equations were then combined by averaging their slopes and assuming that the final equation ran through their mean value at $4\frac{1}{2}$ min. of practice. Performance (i.e., percent time spent on target) = 1.395 times (number of trials) + 6.84, fits these two curves fairly closely, and provides a baseline (*A*) from which to compute the various derived measures for the $\frac{1}{2}$-, 1-, and 3-min. pre-rest practice groups.

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[1] In the method of average decrement as here used, the slope is the average slope of lines joining all adjacent trial values included within the segment of the curve being fitted. With slope determined, the line is assumed to pass through the point of intersection of the lines representing the vertical and horizontal means of these values.

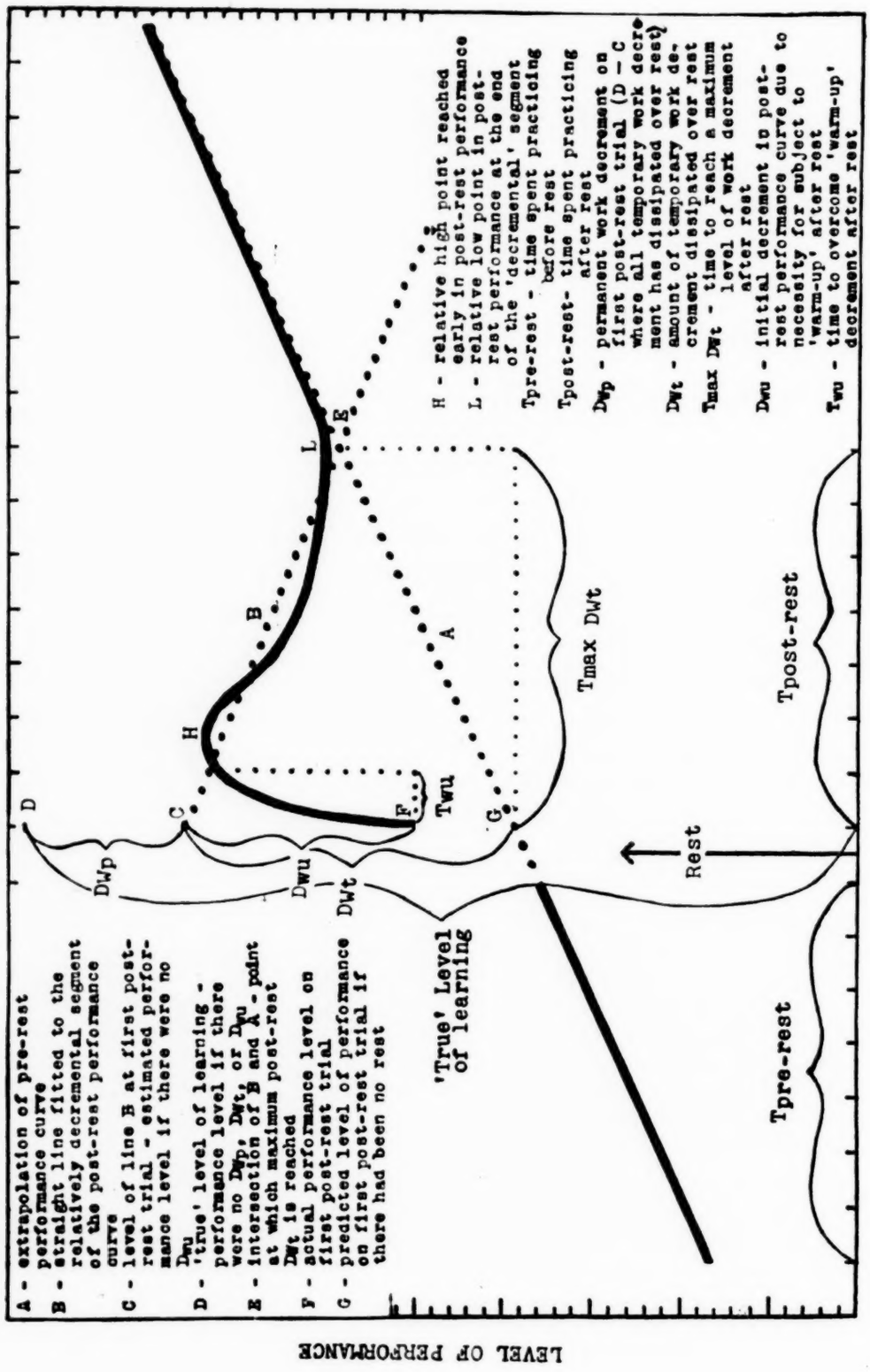

A - extrapolation of pre-rest performance curve
B - straight line fitted to the relatively decremental segment of the post-rest performance curve
C - level of line B at first post-rest trial - estimated performance level if there were no Dwu
D - 'true' level of learning - performance level if there were no Dwp, Dwt, or Dwu
E - intersection of B and A - point at which maximum post-rest Dwt is reached
F - actual performance level on first post-rest trial
G - predicted level of performance on first post-rest trial if there had been no rest
H - relative high point reached early in post-rest performance
L - relative low point in post-rest performance at the end of the 'decremental' segment
Tpre-rest - time spent practicing before rest
Tpost-rest- time spent practicing after rest
Dwp - permanent work decrement on first post-rest trial (D − C where all temporary work decrement has dissipated over rest)
Dwt - amount of temporary work decrement dissipated over rest
Tmax Dwt - time to reach a maximum level of work decrement after rest
Dwu - initial decrement in post-rest performance curve due to necessity for subject to 'warm-up' after rest
Twu - time to overcome 'warm-up' decrement after rest
'True' Level of learning
Rest
Tmax Dwt
Tpost-rest
Tpre-rest
LEVEL OF PERFORMANCE
TIME

FIG. 1. Representation of certain rotary pursuit variables

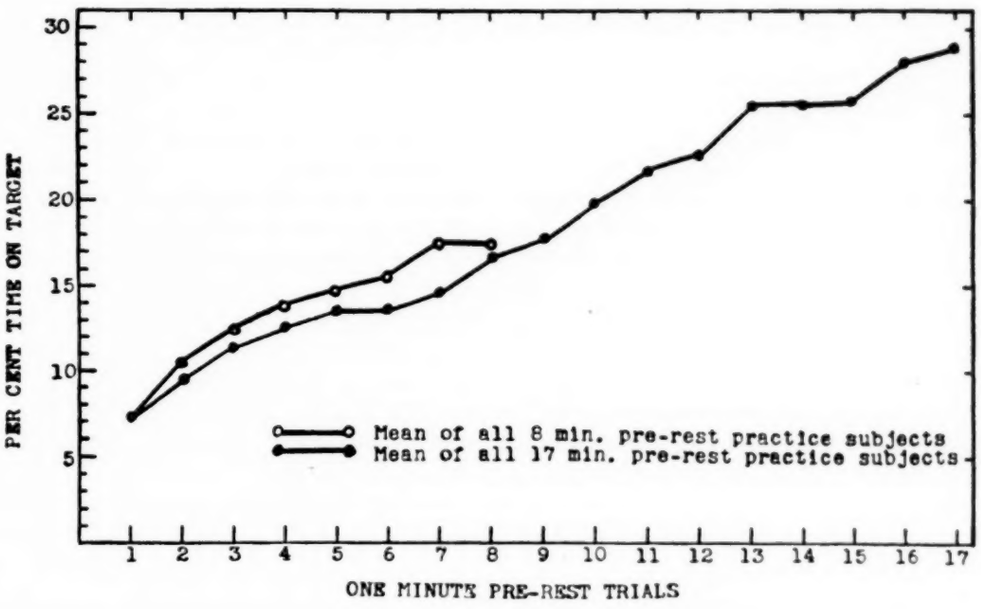

PER CENT TIME ON TARGET
30
25
20
15
10
5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
ONE MINUTE PRE-REST TRIALS
Mean of all 8 min. pre-rest practice subjects
Mean of all 17 min. pre-rest practice subjects

FIG. 2. Mean pre-rest performance curves for all 8- and all 17-min. pre-rest practice Ss

B—straight line fitted by the method of average decrement (see footnote 1) to the relatively decremental portion of the post-rest performance curve, that bounded by and including points *H* and *L*. This procedure was not followed in the case of the ⅓–20–8 group where there was no clearly defined relative high point. In this case, the mean for the third post-rest trial was used as being the high point in most of the remaining 34 curves and hence the best estimate of the high point.

C—level of line *B* at the first post-rest trial. This is the assumed level of performance if there had been no decrement due to the need to warm-up.

D—hypothetical maximum of performance, i.e., the level of performance if there were no temporary or permanent work decrement or warm-up decrement. This would be approximated by a curve obtained under conditions of extreme distribution of practice such as where only one short trial is given per day.[2]

E—point of intersection of lines *B* and *A*. This is used to define how long it takes for post-rest temporary work decrement to build up to an effective maximum (T_{max} D_{Wt}).

F—actual level of performance on first post-rest trial.

G—predicted level of performance on the first post-rest trial if there had been no rest. This is actually the level of line *A* at this trial.

H—relative high point reached early in post-rest performance.

L—'low' point in post-rest performance at the end of the relatively decremental segment.

$T_{pre\ rest}$—the time spent practicing before rest.

$T_{post\ rest}$—the time spent practicing after rest.

D_{wu}—the decrement on any trial due to the necessity for the subject to 'warm-up' after rest. For the first post-rest trial this is the difference between points *C* and *F* in Fig. 1. At any trial D_{wu} will be the vertical difference between line *B* and the post-rest performance curve where line *B* is higher.

T_{wu}—the time necessary to warm up after rest, or to overcome initial post-rest warm-up decrement. This will be the time necessary for the actual performance curve and line *B* to intersect (see footnote 2).

D_{Wt}—the amount of temporary work decrement *dissipated* over rest. This is the difference between points *C* and *G* in Fig. 1.

Total temporary work decrement is equivalent to the maximum D_{Wt}, given sufficiently long rest periods. This point is reached when the curve of D_{Wt} as a function of duration of rest has reached its asymptote. Decrement is present at all points in practice but can be measured only by the introduction of a rest period sufficiently long to insure its relatively complete dissipation.

[2] This variable will not be discussed in this paper, but is included to complete the description.

Then by eliminating D_{wu} (by extrapolating line *B* backward) it is possible to estimate the total temporary work decrement present at the end of the last pre-rest trial. *Reminiscence* or gain over rest is due to this dissipation of temporary work decrement. No implication is intended that temporary work decrement is due to fatigue as commonly defined. The fact that marked decrement as here defined was found in this experiment after only one minute of rotary pursuit practice seems to show that fatigue is not the major factor involved.

$T_{max}\ D_{Wt}$—the time necessary to reach an effective maximum level of temporary work decrement in post-rest practice. This is defined as the time to reach point *E*.

D_{Wp}—permanent work decrement. On the first post-rest trial this will be the difference between points *C* and *D* in Fig. 1 providing there is no temporary work decrement remaining after rest. If some temporary work decrement remains after rest, part of the difference between *C* and *D* will be due to its presence. There will be an amount of D_{Wp} at every point in performance, which can be measured only by introducing a rest to eliminate the decremental effect of temporary work decrement completely and comparing initial post-rest performance corrected for D_{wu} with that of a control group with short trials and long rests (see explanation of *D*). The difference, by definition, would be due to D_{Wp} (see footnote 2).

Problem

The present experiment was designed to determine empirically the following relationships in rotary pursuit learning:

1. The amount of temporary work decrement dissipated during rest (D_{Wt}), as a function of the duration of pre-rest practice ($T_{pre\ rest}$) and of the duration of interpolated rest.
2. The amount of post-rest practice time necessary for temporary work decrement to build up to its maximum ($T_{max}\ D_{Wt}$), as a function of the duration of pre-rest practice ($T_{pre\ rest}$) and of the duration of interpolated rest.
3. The initial amount of post-rest 'warm-up' decrement (D_{wu}), as a function of the duration of pre-rest practice ($T_{pre\ rest}$) and of the duration of interpolated rest.

Experimental Method

Subjects

In view of the finding by Buxton and Grant (3) of motor performance differences between male and female *Ss*, and the desire for as homogeneous a group as possible, only undergraduate women were used. A total of 556 *Ss* participated; 36 were discarded in matching the groups, one person was sent away because of self-reported faulty vision, and nine records were discarded due to recording difficulties. The final analysis was based on the records of 510 *Ss*, 14 in each of 34 groups, and 34 in one group. All *Ss* were naive to this apparatus, although some had seen similar apparatus in the motion picture 'Winged Victory.' The first 315 *Ss* were assigned at random to the 35 groups, while the remaining were assigned systematically without a halt in the practice itself after ½ min. practice, to equate the groups more closely. Mean scores for the first min. or ½ min. of pre-rest practice for the 35 groups can be found in Table I. The closeness of the matching is evident.

Apparatus

Two Koerth-type pursuit rotors, two hinged styluses, four .001 min. Standard Electric stopclocks, and a control unit were used.[3] Each rotor consisted of a flat brass target 1.9 cm. in di-

[3] This equipment was in the laboratory on loan from the School of Aviation Medicine for several other special research projects.

ameter, set flush 8.1 cm. from the center of a bakelite disk 27.7 cm. in diameter. During practice periods, the disk turned clockwise in a horizontal plane at 60 r.p.m. Light hinged styluses allowed no more than the pressure of their own weight on the revolving disk. The control unit automatically switched the recording of stylus-target contacts from one pair of clocks to the other every 20 sec., allowing continuous recording during trials. Although recording was done by 20-sec. periods, data for all the longer practice periods were combined by one-min. intervals to increase the stability of the curves. The two rotors were placed so that the two *S*s practiced side by side, separated by about five ft., standing at right angles to the *E*'s table.

Procedure

The basic unit in all distributed practice is probably work-rest-work. Rather than complicate the situation by introducing a series of rests during practice, it was felt that the variables could best be investigated where this basic unit was adhered to and only one rest introduced.

The 35 conditions used were all possible combinations of ⅓-, 1-, 3-, 8-, and 17-min. pre-rest continuous work periods and ⅓-, 2-, 5-, 10-, 20-, 60-, and 360-min. rest periods. All *S*s worked

TABLE I

PERCENT OF TIME ON TARGET DURING ALL TRIALS FOR ALL GROUPS

Groups	Trial Number	Amount of Rest (minutes)						
		⅓	2	5	10	20	60	360
	1	6.1	5.9	6.2	6.1	6.3	6.2	6.1
⅓ min. pre-rest practice	1	10.8	11.4	11.6	15.1	15.6	15.9	12.7
	2	11.5	12.3	15.5	16.1	17.0	13.9	14.6
	3	14.2	14.1	20.2	18.9	17.9	15.6	15.3
	4	14.2	13.2	22.0	24.4	18.0	17.1	16.0
	5	16.1	15.1	21.9	23.8	19.7	14.8	15.9
	6	16.2	16.4	20.4	24.7	20.0	17.2	18.2
	7	15.9	15.6	18.1	28.0	19.0	15.9	20.2
	8	17.5	17.9	21.9	23.3	22.3	17.9	18.8
	1	7.0	7.5	6.8	7.6	7.4	7.0	7.2
1 min. pre-rest practice	1	12.2	16.5	23.2	22.0	22.8	19.7	21.6
	2	11.9	17.5	25.6	25.7	28.4	20.3	23.5
	3	13.2	17.7	24.0	24.7	27.0	20.4	24.9
	4	13.7	18.3	22.6	25.3	24.4	23.3	24.7
	5	13.8	18.0	24.4	22.2	23.9	21.4	23.0
	6	15.2	17.3	24.7	20.8	24.6	18.9	22.9
	7	17.9	16.1	19.3	20.7	20.8	20.3	23.9
	8	19.8	18.3	22.2	22.3	18.3	22.0	25.7
3 min. pre-rest practice	1	7.4	7.2	7.6	7.3	7.1	7.0	7.4
	2	14.6	7.6	9.5	10.1	10.1	7.5	9.1
	3	18.3	9.4	8.9	13.1	13.1	8.5	10.1
	1	20.5	22.3	28.4	30.2	31.9	26.8	30.6
	2	21.1	23.7	34.3	33.9	37.2	28.5	33.5
	3	24.6	23.5	27.5	31.0	39.1	26.4	33.0
	4	24.1	17.6	25.9	31.0	33.2	24.0	30.4
	5	24.5	19.1	23.7	29.0	31.5	23.0	27.4
	6	22.9	20.5	23.2	24.6	30.3	20.4	26.6
	7	25.3	21.9	22.9	24.1	26.7	20.6	27.9
	8	31.6	22.9	20.3	22.7	25.3	17.2	29.5

TABLE I—*Continued*

Groups	Trial Number	Amount of Rest (minutes)						
		⅓	2	5	10	20	60	360
8 min. pre-rest practice	1	7.3	7.4	7.7	6.7	7.4	7.1	7.3
	2	11.5	13.5	11.6	8.2	12.2	9.7	7.5
	3	14.2	16.7	14.6	10.2	13.5	7.4	11.0
	4	15.3	18.0	16.7	9.9	17.0	9.6	11.8
	5	17.2	15.8	17.4	10.7	19.7	9.0	14.9
	6	16.2	18.0	19.8	11.5	18.4	10.4	16.0
	7	17.9	20.4	19.6	13.3	23.3	11.1	17.9
	8	20.2	16.7	19.0	14.9	21.2	15.2	14.8
	1	25.9	39.0	47.3	37.3	44.1	42.0	39.2
	2	21.7	41.4	52.3	47.7	53.4	46.4	49.0
	3	23.8	40.1	51.0	46.7	51.6	45.9	47.0
	4	27.6	33.3	44.6	44.1	48.0	43.7	45.4
	5	28.2	32.6	38.6	39.5	49.3	39.0	42.4
	6	28.7	33.1	39.2	34.2	45.6	35.4	40.2
	7	28.6	32.2	41.0	34.0	42.1	32.0	40.0
	8	29.4	32.0	39.5	33.8	38.0	33.2	38.7
17 min. pre-rest practice	1	7.4	7.1	7.3	7.2	7.3	7.3	7.1
	2	8.4	11.1	9.4	8.5	11.2	9.3	8.3
	3	9.4	12.9	9.5	7.5	16.8	13.8	11.4
	4	11.1	13.1	12.4	9.0	18.0	14.5	11.6
	5	12.2	14.7	12.9	10.9	16.7	14.6	13.5
	6	12.3	14.0	12.9	11.5	16.8	13.1	14.8
	7	12.7	14.6	14.6	12.6	19.7	11.2	17.3
	8	13.0	17.2	15.0	18.7	20.9	14.1	19.4
	9	16.1	17.9	13.2	20.4	21.5	16.5	18.5
	10	16.5	21.7	14.8	23.2	22.7	19.8	19.1
	11	17.4	23.8	18.9	21.9	25.2	24.1	21.0
	12	20.0	23.7	19.4	25.2	24.7	22.5	22.1
	13	25.0	25.7	23.4	25.9	28.1	26.9	24.1
	14	22.9	24.9	24.9	25.0	26.6	26.2	28.5
	15	23.1	24.5	24.2	25.4	30.2	26.6	27.4
	16	23.0	29.6	27.7	26.5	30.8	29.7	29.5
	17	25.7	29.3	28.4	28.2	34.3	28.8	28.7
	1	31.8	43.6	43.7	46.6	51.9	47.2	41.5
	2	31.5	46.5	48.4	54.4	56.1	56.9	52.6
	3	33.5	41.7	46.6	51.0	54.0	55.5	50.7
	4	32.3	36.9	40.7	48.7	53.2	56.5	49.1
	5	31.5	36.2	40.9	49.9	50.7	51.4	49.7
	6	33.1	34.4	42.5	47.3	50.1	48.4	45.8
	7	34.5	36.4	37.9	45.8	48.1	48.0	45.9
	8	35.4	36.8	37.3	42.1	45.1	46.1	43.9

continuously for eight min. after rest. Adopting the notation that 1–10–8 refers to the condition with one min. work, 10 min. rest, and 8 min. work, the 35 conditions can be schematized as follows:

⅓–⅓–8	⅓–2–8	⅓–5–8	⅓–10–8	⅓–20–8	⅓–60–8	⅓–360–8
1–⅓–8	1–2–8	1–5–8	1–10–8	1–20–8	1–60–8	1–360–8
3–⅓–8	3–2–8	3–5–8	3–10–8	3–20–8	3–60–8	3–360–8
8–⅓–8	8–2–8	8–5–8	8–10–8	8–20–8	8–60–8	8–360–8
17–⅓–8	17–2–8	17–5–8	17–10–8	17–20–8	17–60–8	17–360–8

Ss participated in only one work-rest-work practice cycle, working in pairs. The only exceptions to this were 29 *Ss* with records retained in the analysis who worked alone in the post-

rest period due to schedule conflicts. These *Ss* were fairly well distributed over the conditions, a maximum of five appearing in any one condition.

All *Ss* were told of the general nature of the test and of its use as a coordination aptitude test. As they arrived for the experiment proper, they were given instructions embodying the following points: To attempt to keep the stylus on the target as it rotated, not to press down on the stylus, to follow the target with a relaxed swinging movement of the arm (demonstrated), and to relax the body to avoid becoming fatigued. Their grips on the styluses were examined and corrected where necessary, and after a 10-sec. warning, the rotor was started. When at any time in practice the instructions were violated, *S* was asked to correct her performance. This happened with about one-third of the *Ss* but never interrupted practice for more than five sec. Brief encouraging remarks were made to *Ss* about every six min. but at different points in practice for different *Ss*. It was felt that *Ss* with a continuous pre-rest practice session of 17 min. should receive periodic encouragement, and to be consistent, the same procedure was followed with the other groups.

Ss spent the shorter rest periods in reading magazines or conversing, but were dismissed to carry on their customary activities during the 60- and 360-min. rests. Before post-rest practice, all *Ss* were encouraged to do as well as they could.

Many studies of motor learning are handicapped by a gradual flattening of the performance curve as a ceiling is approached in performance. Such a flattening would of course make impossible the comparison on an absolute basis of otherwise comparable data. This study is designed to investigate levels of performance sufficiently low to avoid this ceiling effect. Examination of the performance levels reached under the various conditions (Figs. 3A and 3B) shows that no mean curve came near the ceiling, and a check over individual records showed no individual *S* averaging more than 80 percent time on the target during her best two min. of practice.

Results

General characteristics of the data

Figs. 3A and 3B give the post-rest performance curves for the 35 experimental groups. The actual values of all points on all curves are given in Table I. Inspection of the graphs indicates that they rather uniformly show phenomena mentioned previously in this paper as found in many post-rest rotary pursuit performance curves: initial level higher than pre-rest performance, quick rise of performance during the first few post-rest trials, and a subsequent segment of the curve showing relative decrement. Recovery after this relative decline can be easily identified in 16 of the 35 curves ($\frac{1}{3}$–5–8, $\frac{1}{3}$–20–8, 1–$\frac{1}{3}$–8, 1–2–8, 1–5–8, 1–10–8, 1–60–8, 1–360–8, 3–$\frac{1}{3}$–8, 3–2–8, 3–360–8, 8–2–8, 8–5–8, 8–60–8, 17–$\frac{1}{3}$–8, 17–2–8) and presumably would have occurred in all if post-rest practice had continued beyond eight min.

The mean pre-rest performance curves for all 8- and 17-min. groups are given in Fig. 2. Spence, Buxton, and Melton (7) obtained a rotary pursuit performance curve over eight min. of continuous practice for 60 women college students. Their *Ss*, working with the same apparatus and under similar conditions, reached performance levels of 11.2 percent and 14.9 percent after four and eight min. practice, while those in this experiment reached 13.5 per cent and 17.1 percent respectively. Reyna's continuous practice group (6) of 64 women college students reached a level of 13.0 percent after 3$\frac{1}{3}$ min. practice, as compared with the 12.6 percent reached by

this group. It would seem from this close correspondence that the present *Ss* are a fairly typical sample of women college students.

Reminiscence as a function of the duration of pre-rest practice and length of interpolated rest

Before beginning an analysis of the present data in terms of the 'new' variables proposed, they will be analyzed from a more conventional point of view. Reminiscence is defined here as the gain on the first

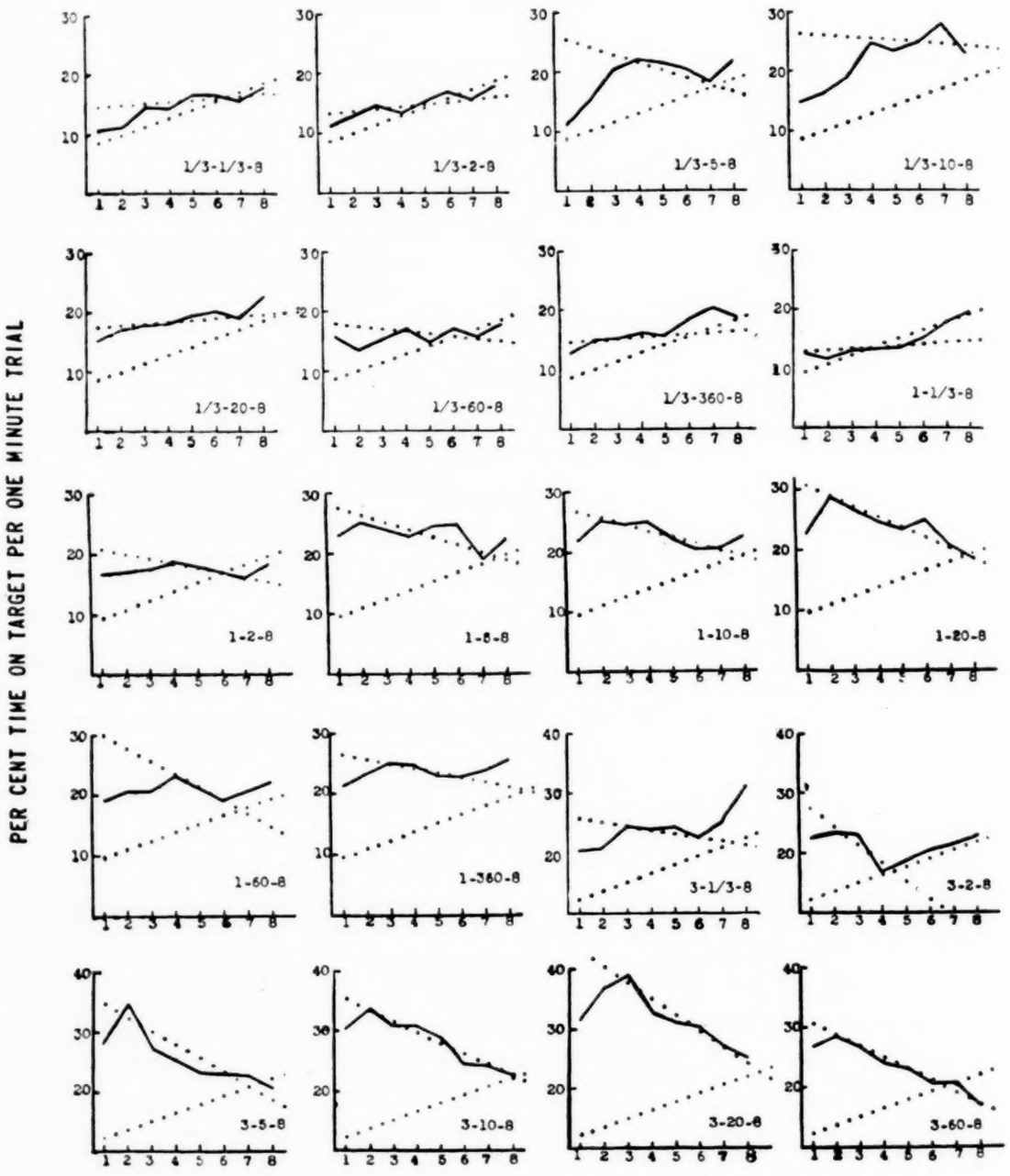


FIG. 3A. Post-rest performance curves

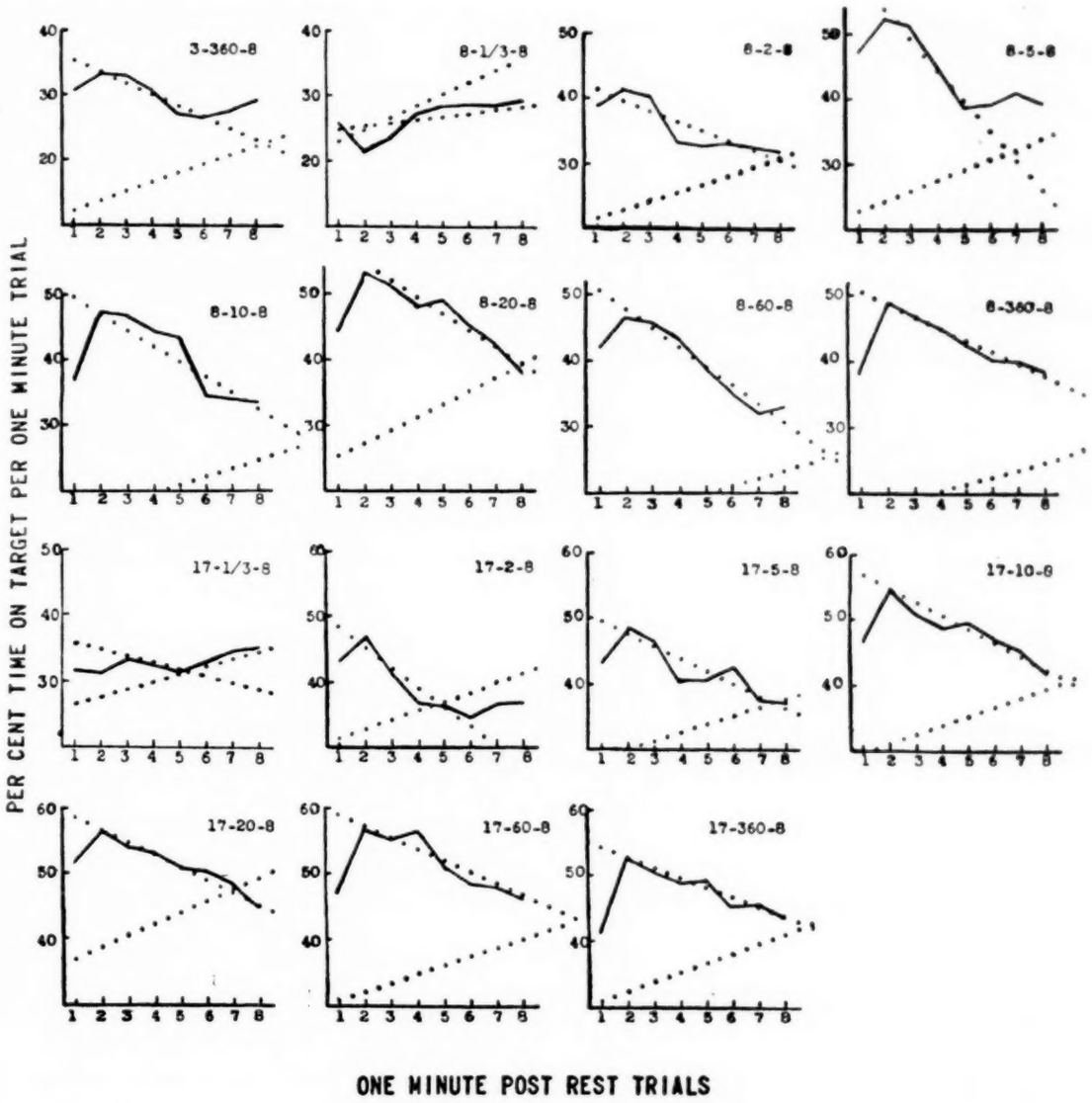


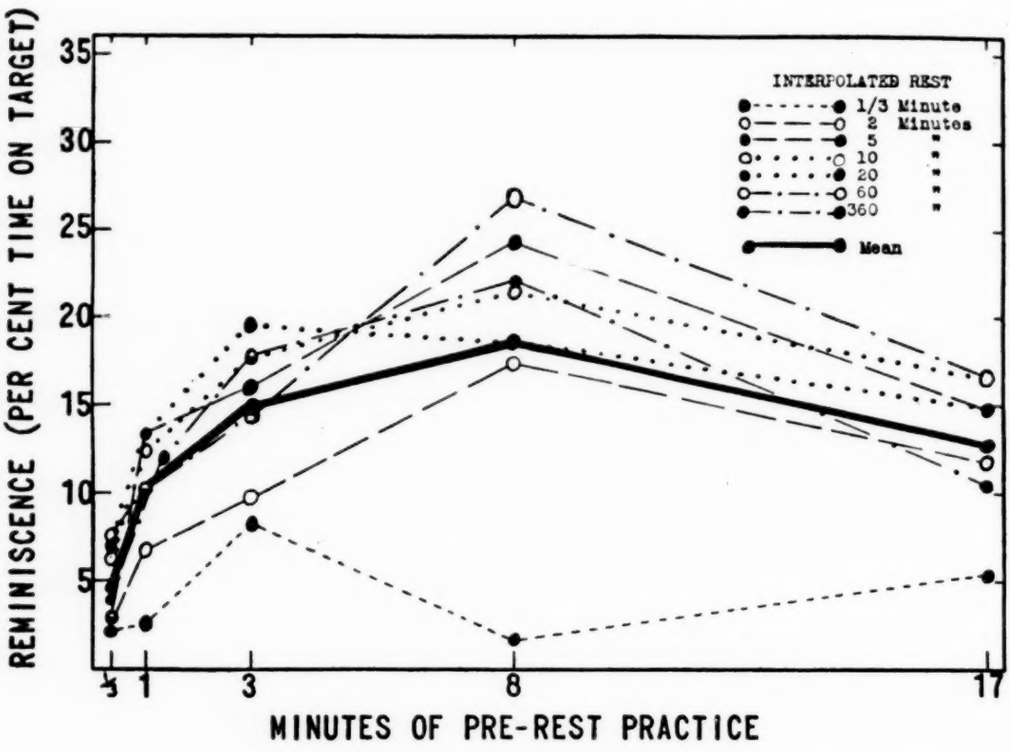
FIG. 3B. Post-rest performance curves

post-rest trial over the level on this trial if no rest period had been introduced. This is one of the possible definitions of reminiscence mentioned by Buxton (**2**) in his review of studies of reminiscence.

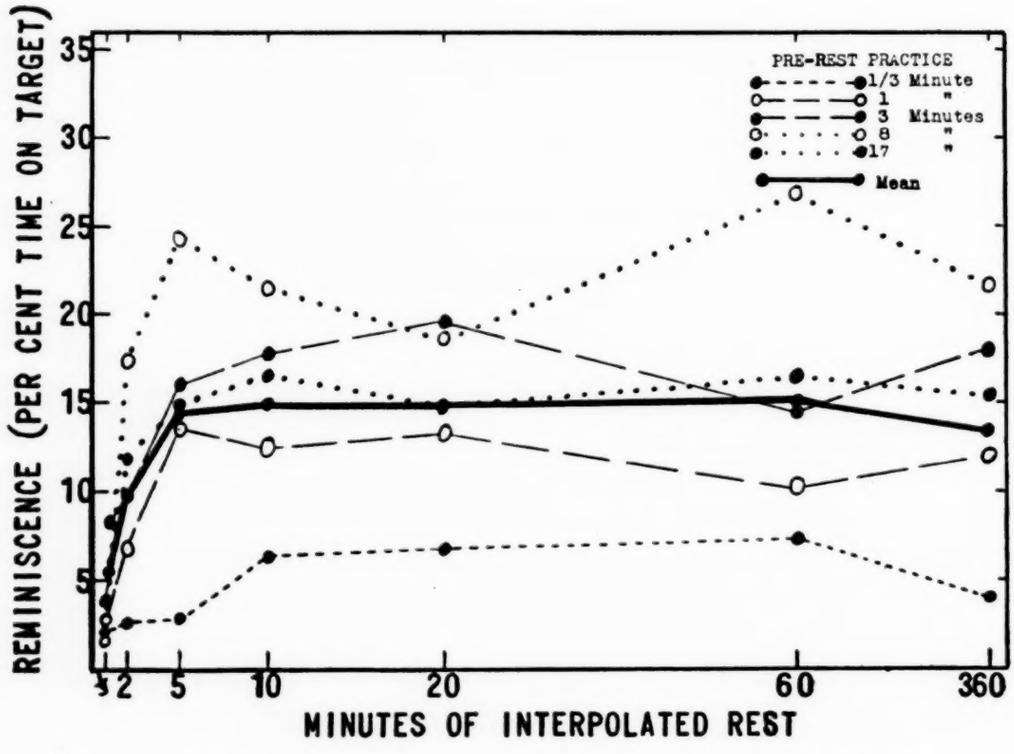
Fig. 4A shows [4] amount of reminiscence as a function of the duration of pre-rest practice ($T_{pre\ rest}$). The amount of reminiscence found after rest increases for eight min., then decreases to 17 min., reaching a level below that after three min. pre-rest practice.

Fig. 4B shows amount of reminiscence as a function of the duration of the rest period. It will be seen that reminiscence as here defined quickly rises to a maximum after five min. rest.

[4] Discussion of the various variables as functions of others will be based on the 'mean curve for all groups.' For example, the mean curve in Fig. 4A represents the mean for all seven rest groups. It is reasoned that all comparable curves should have essentially the same form and the best estimate of this form will be the curve based on the means of comparable points for all groups.



A. REMINISCENCE AS A FUNCTION OF DURATION OF PRE-REST PRACTICE



B. REMINISCENCE AS A FUNCTION OF DURATION OF INTERBOLATED REST

FIG. 4. Amount of reminiscence as a function of duration of pre-rest practice and of duration of interpolated rest

Amount of temporary work decrement dissipated (D_{Wt}) as a function of the duration of pre-rest practice ($T_{pre\ rest}$)

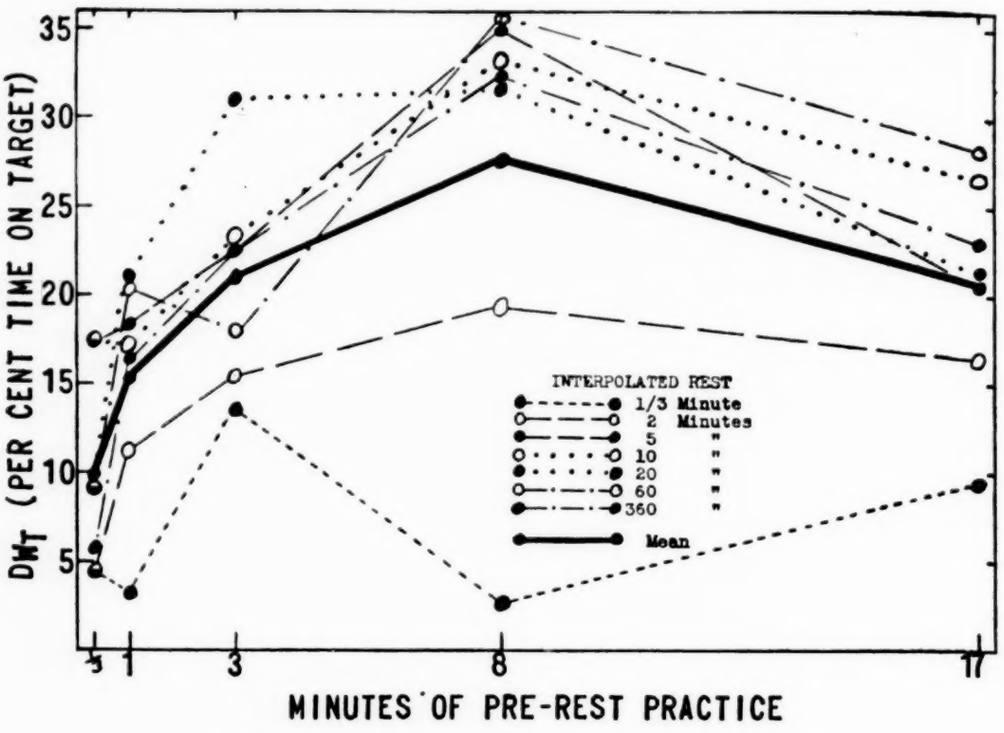
D_{Wt} as a function of $T_{pre\ rest}$ is shown in Fig. 5A. D_{Wt} rises from an assumed zero level with no practice to a maximum level after eight min. continuous practice, then falls off gradually.

It was predicted in a previous paper (1, Deduction 8b) that temporary work decrement would show a negatively accelerated rise to maximum in the course of a practice session. Fig. 5A shows this rise clearly. The decline from eight to 17 min. could be due to the operation of at least two further factors. If the size of increment of temporary work decrement per trial cycle declines, while the proportion being dissipated remains the same, the maximum will decline (1, derivable from Deduction 8a). There may also be some factor such as actual muscular fatigue operating to lower the recovery after 17 min. practice, although it is hard to see why this also would not disappear over a rest period.

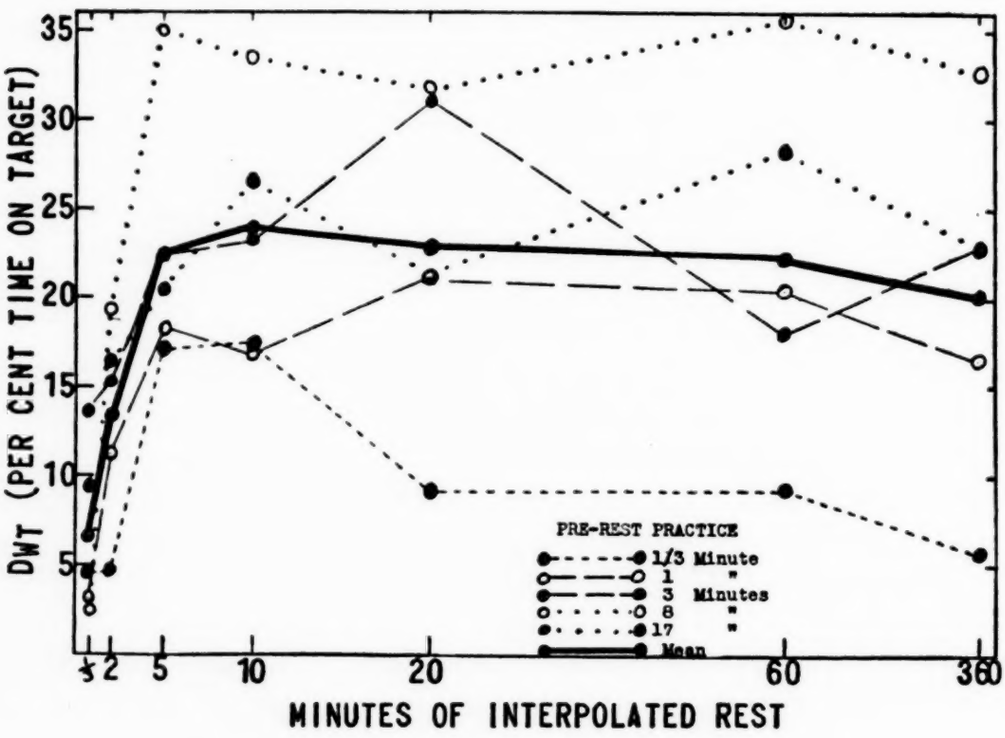
Amount of temporary work decrement dissipated (D_{Wt}) as a function of the duration of the interpolated rest

Since each duration of pre-rest practice ($\frac{1}{3}$, 1, 3, 8, 17 min.) was followed by rests ranging from $\frac{1}{3}$ to 360 min. it was possible to plot D_{Wt} as a function of the duration of rest. On the basis of the mean curve (Fig. 5B) we can conclude that temporary work decrement dissipates as an increasing negatively accelerated function of rest, noting that recovery reaches about 60 percent of the total amount recovered after two min. rest, and over 90 percent after five min. rest. Although the individual curves in Fig. 5B are quite variable, all have the rapid initial rise characteristic of the mean curve, approaching maximum dissipation at or before 20 min. rest.

It is interesting to see how this bears on the general problem of distribution of practice. Assume, as the simplest of several possible alternatives, that temporary work decrement builds up with a fairly constant increment during practice (1, Assumption 7) but dissipates as a constant fraction of the total amount present at a given time (1, Assumption 8). The proportionately longer the rest per trial, the greater the time for dissipation of temporary work decrement so, consequently, the greater the fraction of temporary work decrement dissipated. Further, one would expect that where rests are proportionately much longer than work periods, an equilibrium between the two antagonistic processes would be reached earlier in practice, at a point where net increment during work is just balanced by decrement over rest (1, Deduction 8d).



A. D_{WT} AS A FUNCTION OF DURATION OF PRE-REST PRACTICE



B. D_{WT} AS A FUNCTION OF DURATION OF INTERPOLATED REST

FIG. 5. Amount of temporary work decrement dissipated as a function of duration of pre-rest practice and duration of interpolated rest

D_{Wt} in the low or medium levels of performance in rotary pursuit learning reaches an approximate maximum after 20 min. rest and much of this gain is made during the first $\frac{1}{3}$ min. rest. This verifies and provides quantitative value for a prediction (1, Deduction 8f) that D_{Wt} will be a simple negatively accelerated function of the duration of interpolated rest. Actually, these points are quite well fitted by the curve of the exponential equation $D_{Wt} = 23(1-10^{-.22N})$ where N equals minutes of rest after pre-rest practice.

The duration of post-rest practice to reach maximum temporary work decrement ($T_{max\ D_{Wt}}$) as a function of the duration of pre-rest practice ($T_{pre\ rest}$)

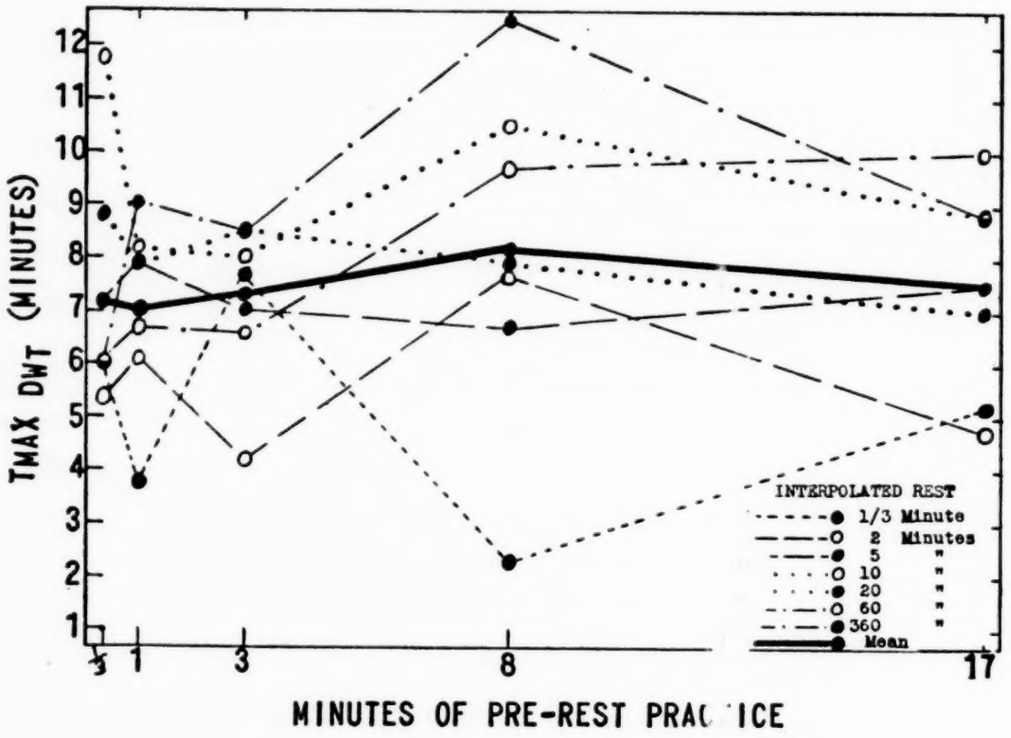
From the graphs of Melton (4) and Pomeroy (5) (see 1, Figs. 2 and 3 for actual graphs), it appears that after an initial period of relative decrement, the post-rest rotary pursuit performance curve starts to rise again. It may be assumed that a temporary decrement due to continuous work has reached its maximum at the point of inversion. If temporary work decrement were almost solely dependent upon the amount of practice subsequent to its dissipation during rest, $T_{max\ D_{Wt}}$ should not be related to $T_{pre\ rest}$ except where, after short rest intervals, some pre-rest temporary work decrement remains.

Examination of Fig. 6A indicates that $T_{max\ D_{Wt}}$ is probably not related to $T_{pre\ rest}$. It was found, using analysis of variance, that the hypothesis that the means lie on a horizontal straight line could not be rejected at even the 20 percent level of confidence.

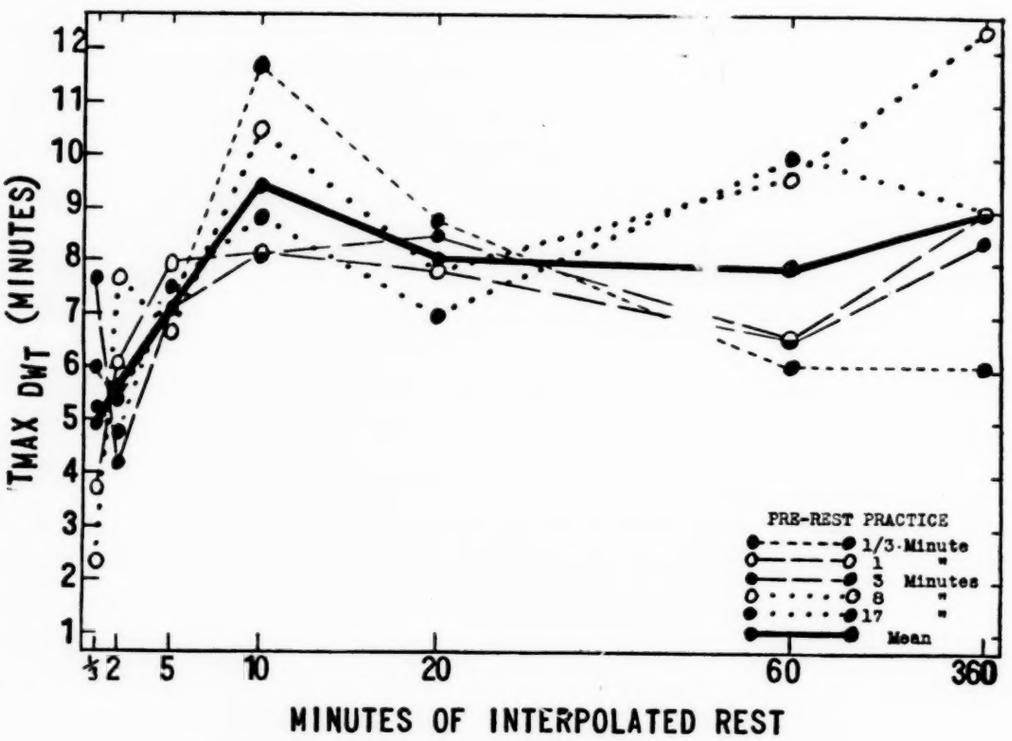
It may be concluded that post-rest $T_{max\ D_{Wt}}$ is about eight min. in continuous rotary pursuit practice. This agrees with the eight min. $T_{pre\ rest}$ necessary to reach the maximum level of D_{Wt}, as shown in Fig. 5A.

The duration of post-rest practice to reach the maximum temporary work decrement ($T_{max\ D_{Wt}}$) as a function of the duration of rest

In a previous paper it was predicted (1, Deduction 8h) that $T_{max\ D_{Wt}}$ should be less, the less temporary work decrement allowed to dissipate during rest. The shorter the interpolated rest, the less opportunity there will be for temporary work decrement to dissipate. The more temporary work decrement present at the start of post-rest practice, the less time it will take for it to reach a post-rest maximum. Fig. 6B shows that in the present experiment this is actually the case—the shorter the rest, the shorter $T_{max\ D_{Wt}}$. This trend is fairly consistent in all individual curves. There is little change in $T_{max\ D_{Wt}}$ after a near maximum level is reached after about 10 min. rest.



A. TMAX DWT AS A FUNCTION OF DURATION OF PRE-REST PRACTICE



B. TMAX DWT AS A FUCTION OF DURATION OF INTERPOLATED REST

FIG. 6. Post-rest time to maximum temporary work decrement as a function of the duration of pre-rest practice and the duration of interpolated rest

Since $T_{max}\, D_{Wt}$ is directly related to D_{Wt}, it would be predicted that the forms of the curves of these variables as functions of duration of rest would be similar. Comparison of the actually obtained data (Figs. 5B, 6B) shows that the curves are actually quite similar, showing sharp initial rises, and coming close to their maxima after 10 min. rest.

To demonstrate the reaching of $T_{max}\, D_{Wt}$ earlier with shorter rests, one can contrast the post-rest performance curve for groups resting a relatively short time and groups resting a relatively long time. Fig. 7 shows the mean post-rest performance curves for all Ss

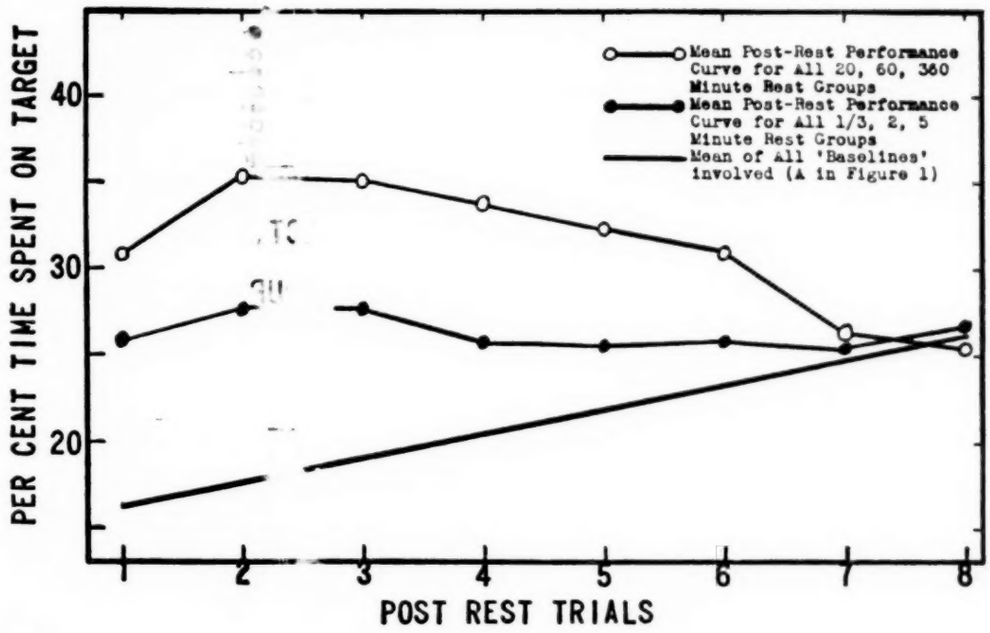


FIG. 7. Mean post-rest performance curves for all 'short' and for all 'long' rest groups

resting $\frac{1}{3}$, 2, and 5 min. and all Ss resting 20, 60, and 360 min. It is apparent that D_{Wt} is less for the shorter rest group and that the curve for this group more quickly returns to the level of the mean baseline.

It may be concluded that post-rest $T_{max}\, D_{Wt}$ is an increasing negatively accelerated function of the duration of rest, and the predicted close relationship of post-rest $T_{max}\, D_{Wt}$, amount of rest, and D_{Wt} actually obtains.

The initial amount of post-rest warm-up decrement (D_{wu}) as a function of the duration of pre-rest practice ($T_{pre\ rest}$)

It may be assumed that D_{wu} is due to loss of 'set' during rest, and that 'set' consists of postural and other muscle responses facilitating performance, acquired during pre-rest practice. As amount of

'set' learned can be assumed to be a negatively accelerated function of $T_{pre\ rest}$, D_{wu} should be a similar function of $T_{pre\ rest}$ (1, Assumption 1).

Examination of Fig. 8A shows that D_{wu} is probably an increasing negatively accelerated function of $T_{pre\ rest}$, although the individual curves are quite variable and the mean curve is irregular. It would seem that the potential amount of D_{wu} reaches its maximum after about eight min. practice—most of the 'set' factors which can be lost during rest have been acquired. It is also possible that D_{wu} is appreciable even before practice since the curve appears to start at a point above zero. This would represent positive transfer of 'set' to this new situation.

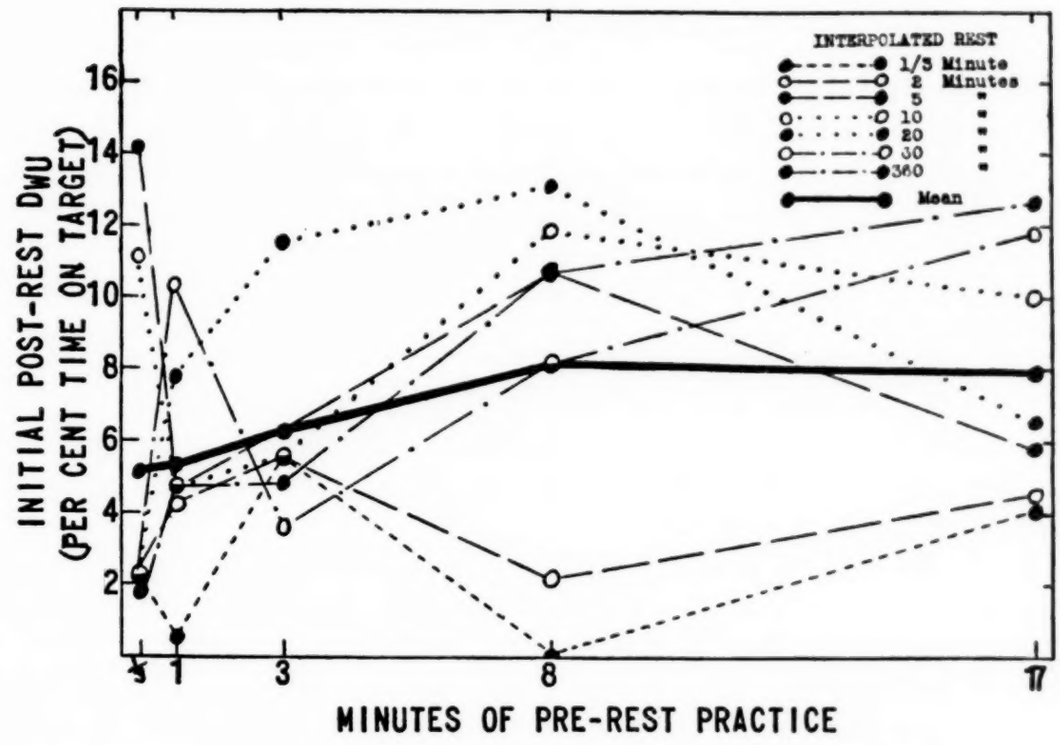
The amount of initial warm-up decrement (D_{wu}) in post-rest practice as a function of the duration of interpolated rest

There will be at first a rapid dropping out of advantageous postural and body adjustments; then the process should slow down—there will be fewer to drop out. On this basis, D_{wu} should be a negatively accelerated function of the duration of rest (1, Assumption 5).

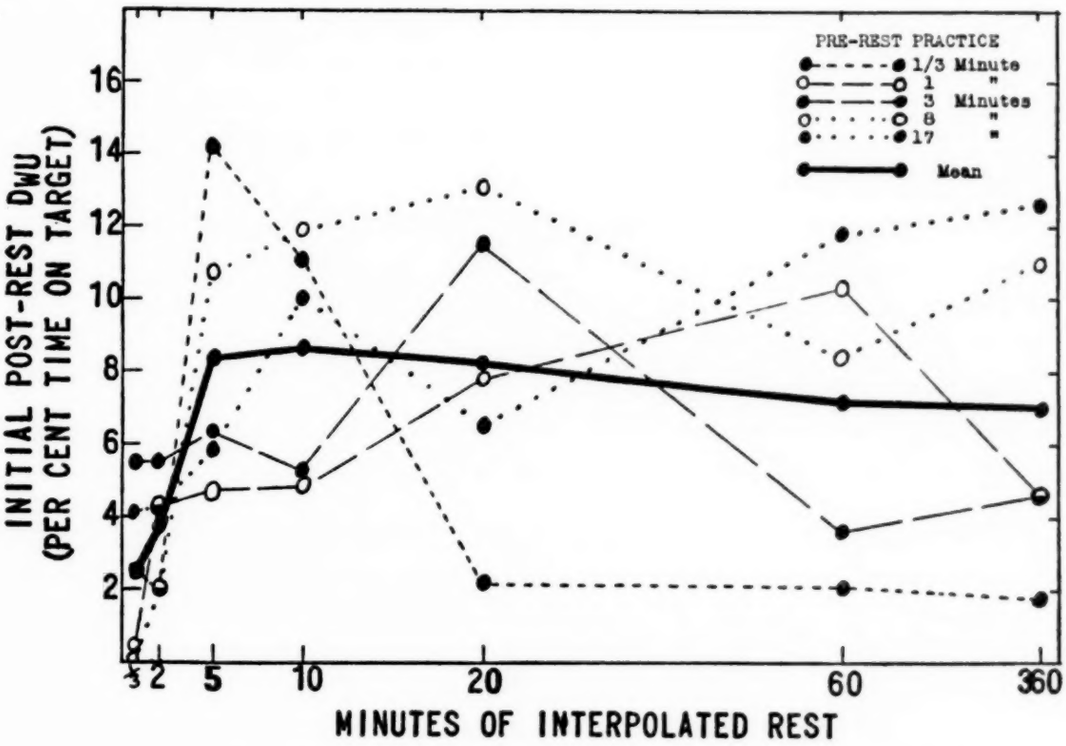
Fig. 8B shows that D_{wu} is an increasing negatively accelerated function of the duration of rest, as predicted, with a maximum reached at approximately 20 min. Although the individual curves are extremely variable, they evidence the same general trend as that shown by the mean curve.

Possible application of findings

This study was designed for preliminary exploration of the empirically determinable interrelations of certain variables. Additional experimentation with varying lengths of rest between trials in pre-rest and post-rest practice should provide information as to the conditions of development of permanent work decrement and serve as a check on the present study. Longer rests, as used by Melton (4), would make possible the study of 'forgetting'—a decline of hypothetical maximum learning in time. Although no extensive attempt has been made in this study to determine actual equations from the data due to rather large variability and the small numbers of cases in each group, even a casual inspection of the various graphs indicates the ultimate feasibility of this approach. Once all important interrelationships have been given precise mathematical expression it should be possible to predict the performance curve for any conceivable distribution of rest and practice intervals.



A. INITIAL POST-REST DWU AS A FUCTION OF DURATION OF PRE-REST PRACTICE



B. INITIAL POST-REST DWU AS A FUCTION OF DURATION OF INTERPOLATED REST

FIG. 8. Amount of initial warm-up decrement as a function of duration of pre-rest practice and of duration of interpolated rest

Summary and Conclusions

Undergraduate women (N = 510) were given $\frac{1}{3}$, 1, 3, 8, or 17 min. continuous practice on pursuit rotors, rested $\frac{1}{3}$, 2, 5, 10, 20, 60, or 360 min., then practiced eight min. more. The data obtained were analyzed to show the effects of duration of pre-rest practice and length of interpolated rest on several variables defined in terms of the rotary pursuit performance curve. It was concluded that for the low and medium levels of learning investigated:

1. Reminiscence is a negatively accelerated function of duration of interpolated rest, reaching a maximum after about five min. rest. Reminiscence reaches a maximum value when rest is introduced after eight min. pre-rest practice.

2. A maximum level of temporary work decrement is reached after approximately eight min. continuous practice, and thereafter the decrement declines somewhat.

3. Dissipation of temporary work decrement (D_{Wt}) reaches an approximate maximum after 20 min. rest, with about 60 percent of this recovery taking place during the first two min. of rest. Its level after varying amounts of rest is fairly well expressed by the exponential equation $D_{Wt} = 23(1-10^{-.22N})$ where N equals minutes of rest after pre-rest practice.

4. Duration of continuous post-rest practice to reach a maximum temporary work decrement ($T_{max}\, D_{Wt}$) is about eight min., and is not related to the amount of pre-rest practice. This agrees well with the eight min. taken to reach maximum temporary work decrement during pre-rest practice.

5. Duration of continuous post-rest practice to reach a maximum temporary work decrement ($T_{max}\, D_{Wt}$) is a negatively accelerated function of the duration of the interpolated rest, with an asymptote at between 10 and 20 min. of rest.

6. Initial amount of warm-up decrement (D_{wu}) is possibly an increasing negatively accelerated function of the duration of pre-rest practice and also of the duration of interpolated rest.

These conclusions confirm, give quantitative value to, and extend generalizations and predictions made in a previous paper. Further experimentation aimed at obtaining exact mathematical equations might well lead to a precise theory of rotary pursuit learning.

(Manuscript received October 25, 1946)

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PLACE VERSUS RESPONSE LEARNING IN THE SIMPLE T-MAZE

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Introduction

In a recent article, the second of a series on spatial learning, Tolman, Ritchie, and Kalish (3) report an experiment designed to separate and to measure the relative importance of two dispositions assumed to play a role in the maze learning of the rat. The two dispositions are (1) that of turning to the right (or the left) at a choice point, and (2) that of moving from the choice point toward the place in the room where the food box has been located. The rat after learning a simple T-maze may make a correct choice because he has acquired either of these dispositions or both of them. However, we are told that in the conventional T-maze it is impossible to determine which disposition is involved, since either or both might be expressed in the same overt behavior. "No experiment has been performed," we quote from the above article, "which has separated these two dispositions."

Let us now examine the experiment of Tolman, Ritchie and Kalish and consider the procedure by means of which they attempted separation. Two groups, of eight rats each, were trained on a combination T-maze shown in Fig. 1. One of the groups, the turning disposition group, called by Tolman, Ritchie and Kalish the response group learned two T arrangements concurrently, S_1CF_1 and S_2CF_2. It will be observed that in both arrangements the choice point occupies a fixed position and that the only successful turn which can be

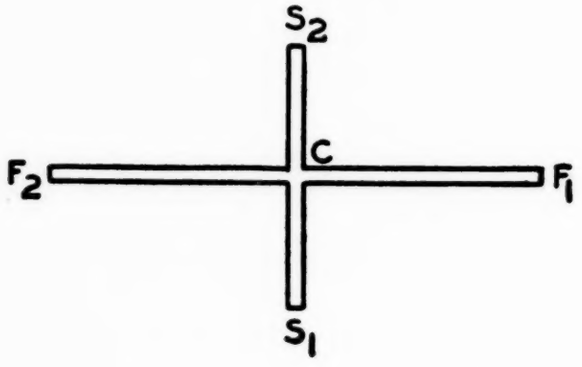

Fig. 1. Reproduction of maze used by Tolman, Ritchie, and Kalish

made at C is a right turn. However, the direction CF_1 differs by 180° from the direction CF_2. Hence it was assumed by Tolman, Ritchie and Kalish that "the maze can be learned *only if* the rats acquire a disposition to turn right."

This analysis seems to us to lack rigor. We do not think that Tolman, Ritchie, and Kalish are justified in asserting that the learning of S_1F_1 and S_2F_2 must be based upon the acquisition of a turning disposition. Instead, to us, three possible interpretations suggest themselves:

1. A turning disposition is acquired. In this case the Tolman, Ritchie, Kalish explanation is correct.

2. Two separate dispositions are acquired: one a disposition to move from C toward *place* F_1, the other, to move from C toward *place* F_2. The fact that these dispositions both involve a right turn at C is incidental and has no effect upon the processes really learned, two directional or place responses.

Two things should be held clearly in mind:

First, though the position of C is fixed, the positions S_1 and S_2 are distinct. They are four feet apart and are likely discriminable to the rat (cf. 1). Moreover the experience flux involved in running from S_1 to C (facing the north side of the room) is probably very different from that involved in running from S_2 to C (facing the south side of the room).

Second, the directional axis CF_1 is discriminable from the axis CF_2 (cf. 1). The rats may have learned to expect different things at C according as they have arrived from start positions S_1 or S_2.

3. Dispositions 1 and 2 both are learned.

But in any case it cannot be said definitely which disposition has been acquired. No separation of the two can rightly be claimed.

The place group of Tolman, Ritchie, and Kalish likewise learned the maze in two arrangements. For some animals this was S_1F_1 and S_2F_1, for others S_1F_2, S_2F_2. The food place chosen for a particular animal was against original preference. It was assumed that since opposite turns lead to the food box the maze could be learned "only if the rats acquired a disposition to go to a constant food location."

This conclusion also seems to us to be unjustified, for in addition to the interpretation offered by Tolman, Ritchie, and Kalish that learning consists of a disposition to go to the food place, we have the following possibility: The rats of the place group may really have learned two turning dispositions, one a disposition to turn left supported upon the distinct place of S_1 and the behavior flux S_1C; the other a disposition to turn right supported on the place S_2 and the

behavior flux S_2C. Finally, it should be added that these possible interpretations are not mutually exclusive.

Summing up, it seemed to us that the failure of the Tolman, Ritchie, Kalish experiment to separate turning disposition and place disposition lay essentially in this fact: discriminable place features were present in each of the two pairs of T arrangements presented for learning. The two *response* arrangements may for example be regarded as two distinct T habits, each having distinctive space supports. And in this case, the learning of arrangement S_1F_1 and again S_2F_2 is in no sense different from the learning of two conventional T-mazes. This likewise holds true when the arrangement for *place* learning is considered.

Accordingly as a first step we sought to devise a set up in which spatial discriminanda could not be used by the rat in learning a simple T-maze. This should give us an instance of learning which would consist of a relatively pure turning disposition. Having, as we believe, arranged a learning situation of this kind, we trained a response group, and for comparison three other groups having access to varying amounts and kinds of spatial support. Two of the three latter groups were trained under conditions approximately like those used by Tolman, Ritchie, and Kalish in training their *response* and *place* groups.

B. *Animals*

Thirty-six rats were used in the experiment. They consisted of descendents of Wistar Strain albinos reared in the colony maintained by the Psychology Department at the University of Texas, and of young albinos purchased from a local dealer. The groups were made up by division of litters. Colony and stock animals were allocated as nearly equally as possible among the groups. During the experiment animals were housed in a colony room adjacent to one of the experimental rooms. Food consisted of Purina Chow. Water was provided at all times in the living cages. Before and during the experiment animals were given sufficient food to permit steady growth. Ages at the beginning of the experiment were approximately 60 days.

C. *Apparatus*

One maze was used in the training of all four groups. It is shown, with dimensions listed, in Fig. 2. The maze was assembled from elevated units, which were interchanged at each run. The units were constructed of dressed pine painted flat black. Dimensions of units were $3\frac{1}{8} \times 24$ in., with track 15 in. above the floor. Food boxes stood at both arms of the T, but food was accessible in only the correct box.

D. *Procedure*

For five days preceding the experiment proper animals were given preliminary training on a four-foot straight elevated path and fed for about three min. in the food box. Both track and food box were the same in construction as those used in the training experiment. Preliminary training was not given in the experimental rooms. The experiment was conducted daily from approximately 2:00 until 4:00 P.M. For all groups training consisted of four trials a day for 12 days. Each rat was run, allowed to eat for approximately 30 sec., then placed in an empty cage

in the colony room while the other members of the group were run. This routine was repeated until each animal had been given four trials. The interval between runs for an individual rat was about ten minutes. Animals of all groups were trained against initial response, i.e., against the response made on the first run of day one. Body length entry into the incorrect arm of the T was scored as an error.

Dome training.—Groups 1 and 2 were trained in a room which we shall call the Dome Room. This room, 20 × 20 × 10 feet, from which all outside light had been excluded, contained a screen dome. The dome, a wooden ribbed structure painted with aluminum paint and covered with 32 gauge wire, was 18 feet in diameter and approximately eight feet high at the central point. The sides of the dome presented a homogeneous appearance, except for one minor irregularity at the place where a door broke the ribbed pattern slightly. Light within the dome was provided by a 75-watt lamp connected in circuit with a Variac by means of which illumination could be cut to zero.

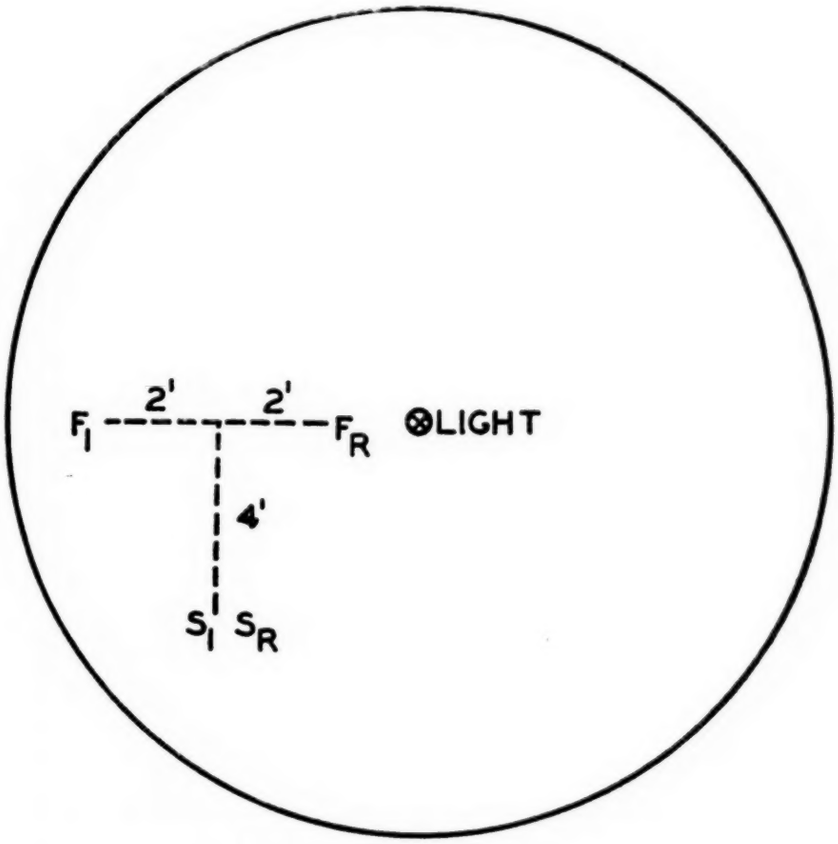

FIG. 2. Placement of maze in training of Group II in dome

Group 1. Dome *response.* 10 animals. This group was trained in the dome under conditions which we believed would prevent use of extra maze spatial supports.

1. For each run the placement of the maze and its axial direction were changed.

2. The Variac was set at a standard position which reduced illumination almost to zero. A person upon going into the dome was unable to see anything except the dim circle of indirect light at the top central area. Sides of the dome and maze were invisible. However, after remaining in the enclosure for 15 to 20 min. one was sufficiently dark-adapted to see the walls of the dome and to see the maze, indistinctly. If a white rat was now placed on the maze, one could follow its movements against the black background of maze and floor and observe its choice at the bifurcation of the T.

In the training of group 1, *E*, having undergone adaptation, signalled to the outside worker who opened a door and handed in a rat. The rat was promptly placed on the starting position and allowed to run the maze. After it had entered the food box *E* again signalled to his coworker who opened the door, took rat and food box, and passed the next animal into the dome.

The co-worker then recorded the response of the first rat, which the experimenter had given orally.

To the visually adapted *E* the only things that could be seen within the dome were the homogeneous pattern of the sides of the dome, the indirect center light, and the outline of the maze. To the unadapted rat it is not likely that anything more than the dim central light was visible. Any relationship between this faint light and the direction of the response to be made at the choice point would have been completely eccentric in view of the variable placement of the maze from run to run. Furthermore, under these circumstances, no cues derived from sound drift within the room, temperature, or other gradients could be utilized. Indeed we suppose that the rat would be about as thoroughly restricted in his use of exteroceptive cues as Honzik's blind, deaf, anosmic animals.[1]

Group 2. Dome (*response and place*). 10 animals. This group was run in the same manner as group 1 except for two points of difference. One, placement of the maze was constant. Its

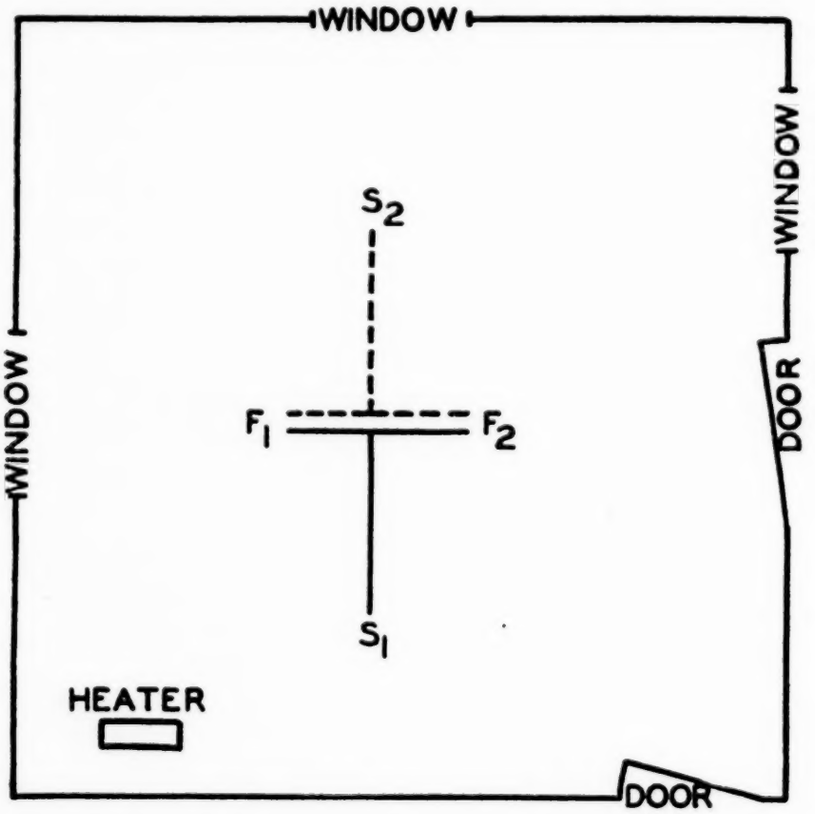

FIG. 3. Placement of maze in training of groups 3 and 4 in room

position was always that shown in Fig. 2. Two, the dome was illuminated by the undimmed 75-watt lamp. Thus, animals of group 2 were given the opportunity to learn either a turning disposition, a place disposition supported upon the slight inhomogeneity of the visual environment, or both. If a place disposition were learned by a right turning rat, this might consist of a turn toward the center of the dome, toward a position under the light, toward the farther dome wall, away from the nearer wall, or some combinatlon of those relationships. For an animal learning a left turn the place disposition would consist of a converse set of relationships.

Room training.—The two remaining groups were trained in a laboratory room 17 × 17 × 10 feet. This room, the plan of which is shown in Fig. 3, contained only the maze set up for a given run $S_1F_1F_2$ *or* $S_2F_1F_2$. Windows were open and artificial illumination was not used.

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[1] In an experiment to be reported soon we trained animals on the Tolman-Honzik maze in the dome described here. Using variable maze placement and dim illumination, we obtained results which almost exactly huplicated those reported by Honzik for blind, deaf, anosmic animals.

Group 3. Room-*response*. Eight animals. This group was trained under conditions similar to those in the training of the Tolman Ritchie, Kalish *response* group. Four of the rats were trained on arrangement S_1F_1, and S_2F_2 (always a left turn), four on arrangement S_1F_2, and S_2F_1 (always a right turn). The schedule of starting positions was S_1, S_2, S_2, S_1; on alternate days it was S_2, S_1, S_1, S_2.

Group 4. Room-*place* group. Eight animals. This group was trained under conditions similar to those used in the Tolman, Ritchie, Kalish *place* group. Five rats learned S_1F_1 and S_2F_1 (food box always toward the west side of the room); three rats learned S_1F_2 and S_2F_2 (food box always toward the east side of the room). Starting positions were S_1, S_2, S_2, S_1 and on alternate days S_2, S_1, S_1, S_2.

E. *Results and Discussion*

Learning curves for all groups are shown in Figs. 4, 5, and 6. These give average error scores for the four daily runs on each day of the training period. The curve of group 1 is given in Fig. 4 and repeated in Fig. 5 to make possible a clearer individual comparison between that group and groups 2 and 3.

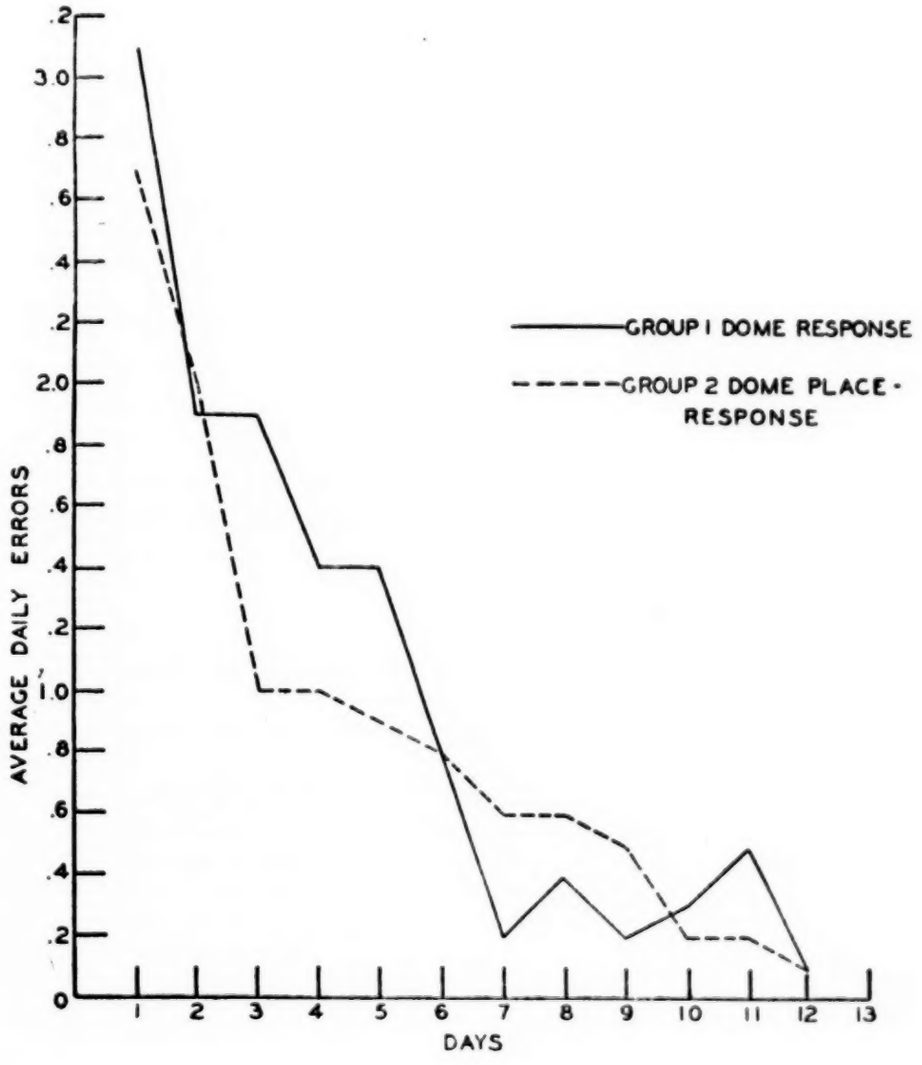

FIG. 4. Learning curves based on performauce of groups 1 and 2

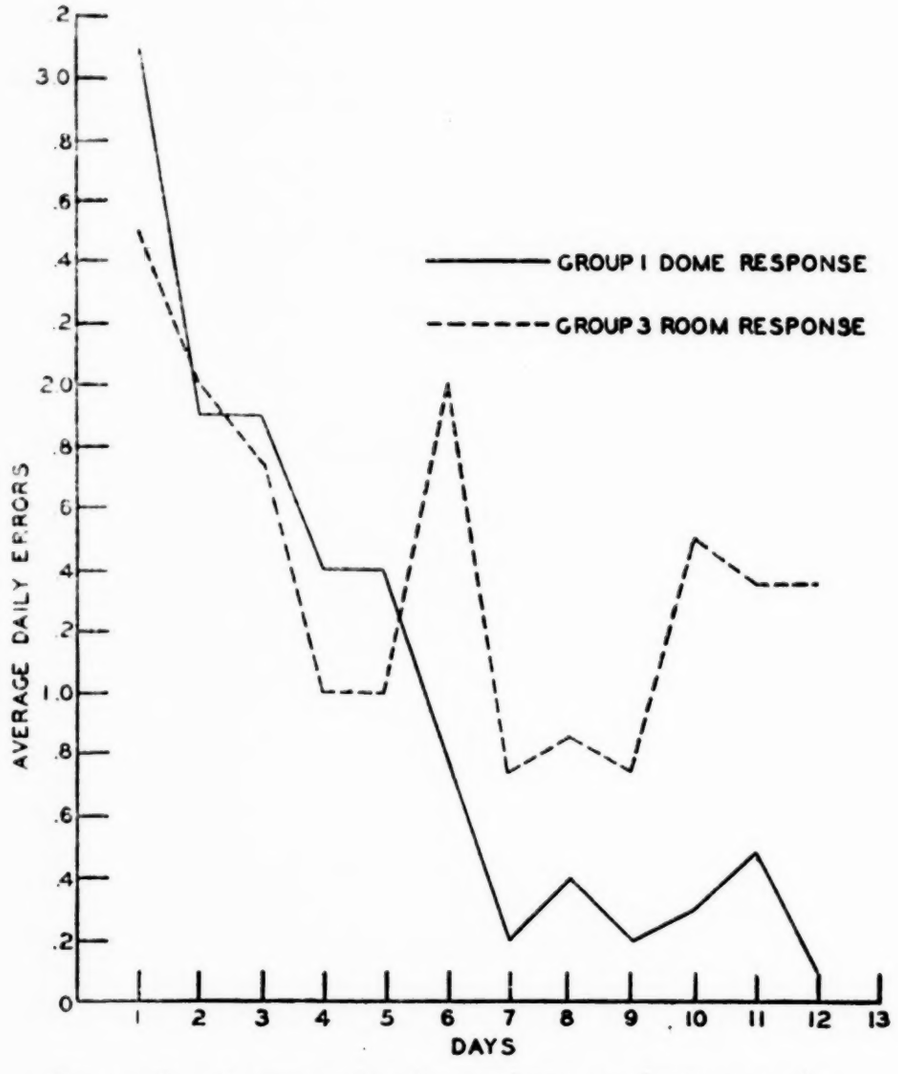

FIG. 5. Learning curves based on performance of groups 1 and 3

Table I shows average total errors for each group for the first half of the training period (days 1–6), differences between groups, and the *t*-values of differences.

TABLE I

AVERAGE TOTAL ERRORS PER GROUP, AND GROUP DIFFERENCES DURING FIRST HALF OF TRAINING (DAYS 1–6)

	Group 2 (Dome place response) Av. = 8.7	Group 3 (Room response) Av. = 10.36	Group 4 (Room place) Av. = 5.88
Group 1 (Dome response) Av. = 10.3	Diff. = 1.60 *t* = .65	Diff. = .06 *t* = .002	Diff. = 4.42 **t* = 2.26
Group 2 (Dome place response) Av. = 8.7		Diff. = 1.66 *t* = .66	Diff. = 2.82 *t* = 1.36
Group 3 (Room response) Av. = 10.36			Diff. = 4.48 **t* = 2.50

* Significant at five percent level of confidence

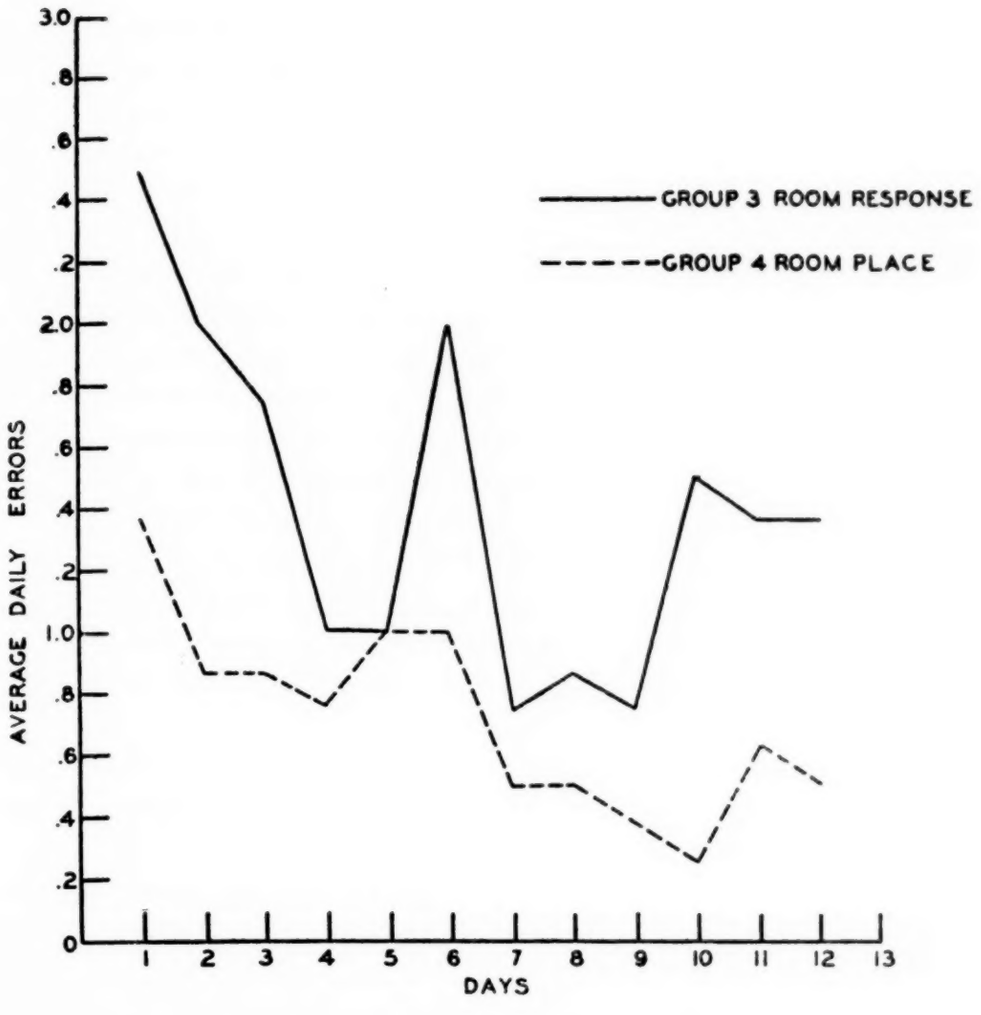

FIG. 6. Learning curves based on performance of groups 3 and 4

Table II shows average total errors for each group for the last half of the training period (days 7–12), differences between groups, and the *t*-values of differences.

TABLE II

AVERAGE TOTAL ERRORS PER GROUP, AND GROUP DIFFERENCES DURING SECOND HALF OF TRAINING (DAYS 7–12)

	Group 2 (Dome place response) Av. = 2.2	Group 3 (Room response) Av. = 6.63	Group 4 (Room place) Av. = 2.75
Group 1 (Dome response) Av. = 1.7	Diff. = .50 t = .54	Diff. = 4.93 **t = 3.20	Diff. = 1.05 t = .99
Group 2 (Dome place response) Av. = 2.2		Diff. = 4.43 **t = 2.97	Diff. = .55 t = .57
Group 3 (Room response) Av. = 6.63			Diff. = 3.88 *t = 2.31

* Significant at five percent level of confidence
** Significant at one percent level of confidence

It is apparent, first of all, that there is general agreement between our findings and those of Tolman, Ritchie, and Kalish. It should be recalled that these writers found their place group to be markedly superior to their response group both in learning rate and in final level of performance. This is likewise shown in the comparison of our room place group and our room response group. In these groups experimental conditions were similar, though by no means identical to those in the Tolman, Ritchie, Kalish experiment. Although we were unable to superimpose the learning curve of their response group upon our response group without extrapolating beyond their 34th trial, it is evident that agreement between the groups is striking. Only three of their eight animals mastered the maze at a criterion of 10 consecutive perfect runs, in 72 trials. In 48 trials five of our eight animals also failed the same criterion, though all but three of these five performed consistently better than chance. And, while our room place group was somewhat slower and more erratic than the Tolman, Ritchie, Kalish place group, it was superior to their response group and to our own room response group.

Of more importance, we believe, are the comparisons between rate of learning of groups 1 and 2, and again between groups 1 and 3. Here two facts stand out.

1. Group 1 learned as rapidly as group 2. At no stage in the training period is there a significant difference between the two groups. Now there seems to us to be little doubt that the dome response animals acquired a response or turning disposition; that for them no place cues were available. Yet they are at no disadvantage when compared with the dome place response group having an environment that is visually inhomogeneous, and, presemably, one that offers distinct place relationships.

2. Group 1 is superior to group 3 in the final level of learning attained. The difference develops slowly but is significant for the last half of the training period.

These findings suggest to us that the poor learning of the room response groups, both the Tolman, Ritchie, Kalish group and our own, is due not to the fact that an isolated turning disposition is acquired slowly, but to the fact that interference is brought about by spatial opposition at the choice point.

F. *Summary*

1. We have first considered the experiment of Tolman, Ritchie, and Kalish in which they undertook to isolate and compare the learning of two dispositions, that of making a right turn, and that of orienting toward the food place. These writers, employing a double

T-maze arrangement, trained two groups of rats, a response group and a place group. The problem set for the response group, starting variously at one of two fixed positions, was always to turn right at the choice point. This involved going one time to the east side of the room, another time to the west side. The place group went always to the east (or west) side of the room, but turned right on one trial and left on another. Tolman, Ritchie, and Kalish reasoned that learning by these groups consisted respectively of the acquisition of a turning or response disposition, and of a place or orientational disposition. Since the learning of the place group was superior to that of the response group they concluded that "in situations where there are marked extra-maze cues, place-learning is simpler than response-learning."

2. In the present paper we have contended that the conclusion of Tolman, Ritchie, Kalish is not rigorous since there seems to us to be a possibility that their response group learned place dispositions, and that their place group learned response dispositions.

3. We undertook a further study using a T-maze similar to that used by Tolman, Ritchie, and Kalish. In our experiment we used four groups of rats. The first group (N = 10) was trained with variable maze placement in a dome-like enclosure dimly illuminated. Since any relationship between extra-maze cues and the turn to be made at the choice point was changed at each trial, we consider that these animals could have learned only a turning disposition. Our second group (N = 10) was also trained in the dome but with fixed maze placement, and with illumination provided by a 75-watt lamp. The turn at the choice point was constant. This group, therefore, could have acquired a place disposition, a turning disposition, or both. The third group (N = 8) was trained in a laboratory room under conditions similar to those used in the Tolman, Ritchie, Kalish response group. The fourth group (N = 8) was trained in the same laboratory room but under conditions like those used in the Tolman, Ritchie, Kalish place group.

4. Group 3 (room response) and group 4 (room place) differed significantly in amount of learning shown, group 4 being superior. This finding is in agreement with the finding of Tolman, Ritchie, and Kalish.

5. Group 2 (dome place and response) showed no superiority over group 1 (dome response).

6. Group 1 (dome response) reached a significantly higher level of learning than group 3 (room response).

7. On the basis of these findings we conclude that the difference between the room response group and dome response groups must be due to the effect of disturbing extra-maze cues in the room situation.

We conclude further that spatial opposition which develops within the room in connection with alternate right and left turns is an important causal factor in the slower learning of the room response when compared with either our dome response group, our room place group, or with the Tolman, Ritchie, Kalish room place group.

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EYELID CONDITIONING AS INFLUENCED BY THE PRESENCE OF SENSITIZED BETA-RESPONSES[1]

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The purpose of the present experiment was to investigate the effects of the presence of sensitized Beta-responses upon the process of eyelid conditioning.

Earlier experiments (**6**, **7**) demonstrated the presence of a secondary response of the eyelid to light. The secondary response was found, under certain conditions, to increase in frequency and amplitude in the same general way that eyelid CR's increase in frequency and magnitude during conditioning reinforcement. This sensitization phenomenon was, furthermore, found to depend upon stimulus intensity (**8**) and degree of dark adaptation (**9**). The secondary response was called the β-response to distinguish it from the primary reflex or α-response of the eyelid to light. The β-response ranged in latency from 120–240 msec., as compared with the α-response which ranged from 50 to 110 msec.

The relationship between the newly-found β-response and the eyelid CR was completely unknown. The two responses seemed to be strikingly alike in frequency, magnitude, and latency (**7**), so that it was natural to hypothesize that they were related or perhaps basically identical. It was therefore decided to carry out the present experiment in which conditioned eyelid reactions acquired when β-responses were present—in dark adapted *S*s—were contrasted with conditioned eyelid reactions acquired when β-responses were absent—in light adapted *S*s.

Apparatus and Procedure

1. *Apparatus.*—The stimulating and recording apparatus was essentially the same as that reported for an earlier study (**9**). It consisted of a modified Dodge photochronograph (**5**) with which were recorded the movements of the right eyelid as magnified threefold by a lever system.

The *S*, whose head was steadied by means of a head-rest and bite-board, looked into a large box-like enclosure. Sixty cm. in front of the *S* was a 10-cm. circular milk-glass window with a black fixation spot in the center. The window was surrounded by a 30-cm. square light-diffusing mat surface. Illumination on this diffusing surface could be controlled so as to permit or prevent dark adaptation of the *S*.

The conditioned stimulus (CS) consisted of illuminating the milk-glass window to a brightness of about 280 millilamberts for a period of about .75 sec. The unconditioned stimulus con-

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sisted of a slight puff of air to the right cornea. The air-puff, when it was given, followed the onset of the light by .45 sec. The interval between trials was spaced randomly between 25 and 45 sec.

2. *Procedure.*—The general plan of the experiment is outlined in Table I. The *S*s, who had volunteered from elementary courses in psychology, were assigned alternately to the dark adapted and non-adapted groups solely on the basis of order of appearance for the experiment. On Day 1, *S*s of both groups were first light adapted for five minutes, as indicated in Table I. They

TABLE I

PLAN OF THE EXPERIMENT

	Dark Adapted Group (Beta frequency maximized) $N = 21$	Non-adapted Group (Beta frequency minimized) $N = 20$
	Day 1 and Day 2 Procedure	
A Light Adaptation Procedure	*Same for both groups. Five min.* visual fixation. Mat surface brightness 38 to 60 millilamberts; milk-glass window about 1500 millilamberts.	
B Visual Fixation Procedure	Visual fixation for *25 min. Enclosure illumination limited to a brightness of .01 millilamberts on milk-glass window.*	Visual fixation for *25 min. Mat surface brightness 38 to 60 millilamberts; milk-glass window brightness 27 millilamberts.*
C Reinforcement Procedure	Conditioned and unconditioned stimulus presented together for 25 reinforcement trials. Lighting conditions as in *visual fixation procedure*, above.	Conditioned and unconditioned stimuli presented together for 25 reinforcement trials. Lighting conditions as in *visual fixation procedure*, above.
	Day 3 Procedure	
A Light Adaptation Procedure	Same as Days 1 and 2 for both groups.	
D Extinction Procedure	*Same for both groups.* Milk-glass window brightness reduced from 1500 to 27 millilamberts. (Mat surface remains at 38 to 60 millilamberts.) One min. delay period. Sixteen extinction trials on which the light stimulus alone is presented, plus four 'control' trials spaced evenly through the extinction trials.	

then went through a visual fixation procedure for 25 min. During this period, *S*s in the dark adapted group were permitted to become dark adapted by the low brightness (.01 millilamberts) of the milk-glass window. In contrast, for *S*s of the non-adapted group, the square light-diffusing surface was illuminated so that they would not become dark adapted. Following the visual fixation procedure was a reinforcement procedure consisting of 25 trials on which the light and puff were presented together. For each group, respectively, the illumination was the same as it had been during the preceding visual fixation procedure. The intermittent flashes of the stimulus light presumably did not interfere seriously with the dark adaptation of the dark adapted group (**18**), so that the reinforcement trials took place under conditions of dark adaptation for this group

and under conditions of light adaptation for the non-adapted group. The Day 1 procedure was repeated for each *S* on Day 2. Then, on Day 3, the experimental procedure was exactly the same for both groups as shown in Table I. First, all *S*s were light adapted as on Days 1 and 2. Then each *S* was given 16 extinction trials with the light alone. During the extinction procedure, the illumination of the light-diffusing surface was such as to prevent dark adaptation. Since there were no differences between groups in the extinction procedure of Day 3, any group differences in CR's appearing during extinction must be traced to the difference in adaptation and the presence or absence of β-responses during the reinforcement trials of Days 1 and 2.

Results

1. *Effectiveness of procedure for controlling frequency of β-responses.* —As stated above, the goal of the light and dark adapting procedures was to minimize and maximize, respectively, the frequency of β-responses in the two groups of *S*s during the reinforcement procedure. That this goal was achieved is shown clearly in Fig. 1. In Fig. 1, the latency distributions of all eyelid responses evoked by the light stimulus are presented separately for the dark adapted and non-

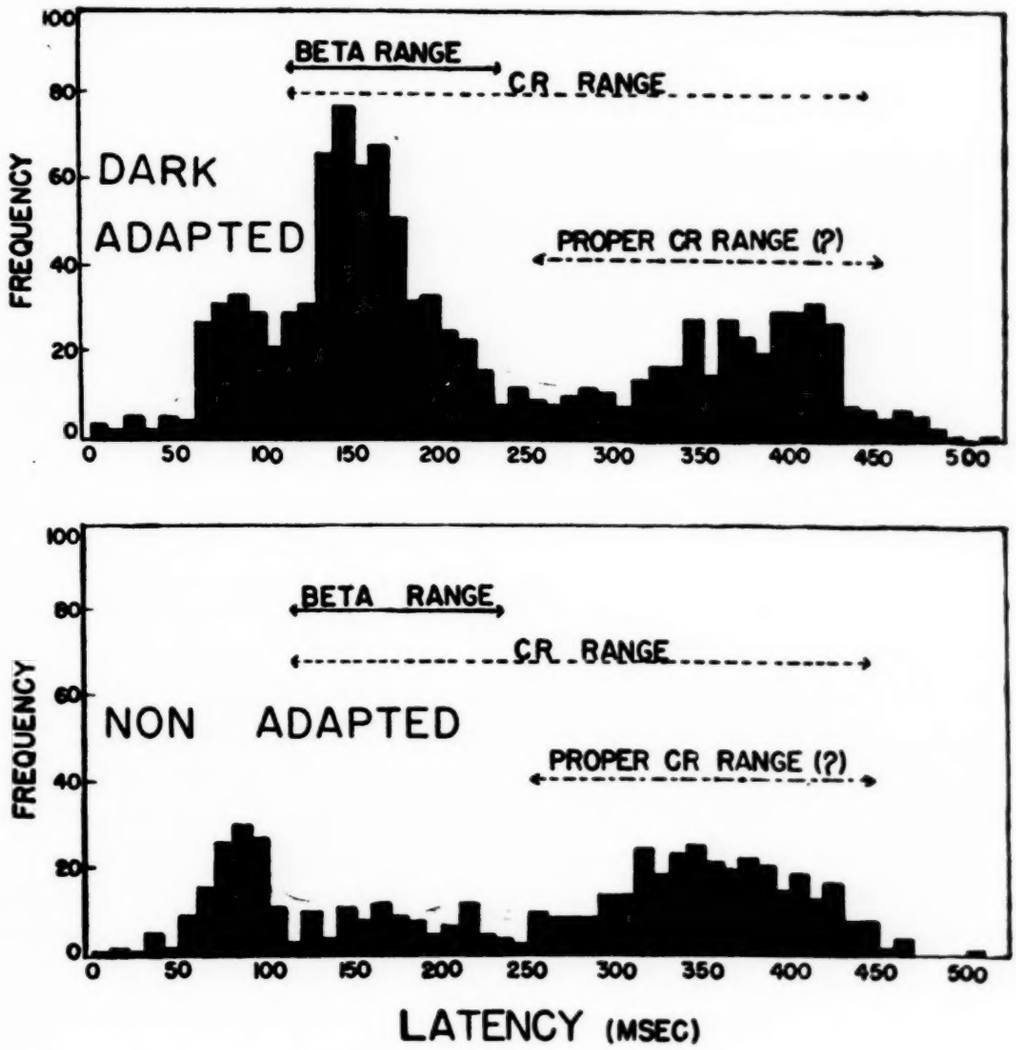

Fig. 1. Latency distributions of all eyelid responses evoked by the light stimulus during the course of the experiment

adapted groups. The absolute frequency of responses is graphed against latency in hundredths of a sec. The first mode of responses between 50 and 110 msec. is made up of α-responses or primary reflexes to light. The second mode between 120 and 240 msec., found only in the dark adapted group, consists of β-responses. The important feature of Fig. 1 is the complete absence of the β-response mode in the latencies of the non-adapted group. The β-responses are simply absent in this group, which shows that the dark adaptation and the non-adaptation procedures had the intended results with respect to maximizing and minimizing the frequency of β-responses.

2. *Frequency and magnitude of responses.*—To facilitate analysis of acquisition and extinction trends, the 25 reinforcement trials on each of the first two days of the experiment were divided into five consecutive five-trial blocks, and the 16 extinction trials on Day 3 were divided into four consecutive four-trial blocks. Following the common practice, the percent frequency of responses in the CR latency range (120–450 msec.) during each of these five-trial blocks is given separately for each group in Table II.

TABLE II

MEAN PERCENT FREQUENCY OF EYELID RESPONSES IN THE CR LATENCY RANGE (120–450 MSEC.) DURING SUCCESSIVE FIVE-TRIAL BLOCKS *

Group	Day 1 Trials (Reinforcement)					Day 2 Trials (Reinforcement)					Day 3 Trials (Extinction)			
	1–5	6–10	11–15	16–20	21–25	1–5	6–10	11–15	16–20	21–25	1–4	5–8	9–12	13–16
Dark Adapted	61	61	58	63	67	68	72	78	76	76	20	15	20	27
Non-adapted	13	20	30	35	39	54	50	46	57	50	39	19	16	8

* Four-trial blocks on Day 3

The data in Table II show that the frequency of responses in the dark adapted group remained high throughout the reinforcement trials of Days 1 and 2, with a slight gain in frequency from Day 1 to Day 2. The CR's of the non-adapted group showed an increase in frequency, particularly on Day 1. On Day 3, the non-adapted group showed frequency decreases. In contrast, there was no decremental trend in the Day 3 data of the dark adapted group. If anything, the usual decremental trend was reversed. The striking difference between groups in frequency trends on Days 1 and 2 may be accounted for by the presence of β-responses which 'contaminate' the conditioning data of the dark adapted group. The non-adapted group, in the absence of β-responses, yielded a classical conditioning acquisition curve on Days 1 and 2.

On Day 3, however, lighting conditions were identical for the two groups, so that differences in frequency of responses must be ascribed to differences which existed between groups during the reinforcement trials of Days 1 and 2. The difference in frequency which favored the non-adapted group on trials 1–4 at the beginning of extinction was significant at the two percent level ($t = 2.46$ for 39 d.f.). The reversed difference on trials 13–16, favoring the dark adapted group was significant at the one percent level ($t = 3.31$ for 39 d.f.). A measure of overall extinction trend may be obtained by subtracting the frequency on trials 13–16 from the frequency on trials 1–4. This was done for each *S*, and the difference between groups in overall extinction trend was found to be significant at the one percent level ($t = 3.93$ for 39 d.f.).

The average magnitude of responses in the traditional CR latency range is given by five-trial blocks in Table III, just as the frequency

TABLE III

AVERAGE MAGNITUDE OF EYELID RESPONSES DURING SUCCESSIVE FIVE-TRIAL * BLOCKS ON DAYS 1, 2 AND 3

Group	Day 1 Trials (Reinforcement)					Day 2 Trials (Reinforcement)					Day 3 Trials (Extinction)			
	1–5	6–10	11–15	16–20	21–25	1–5	6–10	11–15	16–20	21–25	1–4	5–8	9–12	13–16
Dark Adapted	3.26	5.78	4.56	5.15	6.10	7.30	7.35	9.64	11.04	10.53	2.23	1.67	2.42	3.48
Non-adapted	2.48	2.82	3.21	3.42	3.72	7.31	6.56	6.04	7.20	7.51	7.41	3.87	2.28	1.48

* Four-trial blocks on Day 3

data were given in Table II. Partly because of the usual correlation between magnitude and frequency (**3**, **2**, **14**), the data of Table III tend to follow the same trends as the frequency data of Table II. The striking differences between groups are: (A) the greater magnitude for the dark adapted group on Days 1 and 2; and (B) on Day 3, the reversal in the dark adapted group of the extinction trend found with the non-adapted group. The interpretation is the same as that for the frequency data.

The significance of trends and differences in trends of the data of Table III was examined for each day, separately, by means of Alexander's (1) analysis of variance test for trend. The results of the trend analysis are summarized in Table IV. The source of variation is given in the left-hand column and the significance level of the corresponding *F* is given for each day of the experiment in the remaining columns. Table IV shows that on Day 1 there was a significant overall slope, significant variation between individual

TABLE IV

SUMMARY OF THE SIGNIFICANCE OF ACQUISITION AND EXTINCTION TRENDS

Source of Variation	Day 1 Acquisition Trends	Day 2 Acquisition Trends	Day 3 Extinction Trends
Between individual slopes	$P < .005$	$P < .001$	$P < .001$
Between group slopes	$P > .50$	$P < .010$	$P < .001$
Overall slope	$P < .001$	$P < .001$	$P < .005$
Between individual means	$P < .001$	$P < .001$	$P < .001$
Between group means	$P < .001$	$P < .001$	$P < .010$

slopes (linear component) and individual means, and significant variation between group means. The same was true for Day 2; and, in addition, on Day 2 the difference between group slopes was statistically significant. On Day 3 there was highly significant overall slope, highly significant variation between individual means and slopes, *and significant differences between group means and group slopes.*

The results of the foregoing analysis of variance lead to straightforward interpretations. In general, the analysis demonstrates the reliability of the inter-group differences in acquisition and extinction which were mentioned in connection with Table III. Beyond this, the significant variation between individual means and slopes, shows that the differences between individual *S*s with respect to rate of acquisiton and extinction of CR's are reliable. This constitutes a partial corroboration of such observations as those of Porter (**15**, **16**) and Campbell and Hilgard (**3**).

3. *The latency of the conditioned eyelid response to light.*—In reading eyelid CR records, the practice has been to label as CR's all responses occurring after the primary reflex or α-response and before the puff reinforcement (**11**). This latency range is indicated in Fig. 1 as 'CR Range.' Because of the presence of β-responses, the traditional CR range is not homogeneous. There are, in the dark adapted group, two modes of responses between 120 and 450 msec. which suggest breaking down the traditional range into a β-response range (120–240 msec.) and a post-beta range (250–450 msec.). This was done and the frequency and magnitude trends were analyzed separately for the two ranges. The frequency data appear in Table V, separated into five-trial blocks.

In Table V, the frequency of responses in the β-response latency range is irregular and shows little tendency for increment during the reinforcement trials and little tendency for decrement during the extinction trials. (The drop in frequency for the dark adapted group

TABLE V

MEAN PERCENT FREQUENCY OF EYELID RESPONSES DURING SUCCESSIVE FIVE-TRIAL * BLOCKS, SEPARATED ACCORDING TO LATENCY RANGE

Group	Beta Response Latency Range (120–240 Msec.)													
	Day 1 Trials					Day 2 Trials					Day 3 Trials			
	1–5	6–10	11–15	16–20	21–25	1–5	6–10	11–15	16–20	21–25	1–4	5–8	9–12	13–16
Dark Adapted Group	48	50	52	45	50	40	50	59	48	50	8	5	5	6
Non-adapted Group	7	10	14	9	8	13	8	10	6	11	7	3	5	0
Latency Range from 250–450 Msec.														
Dark Adapted Group	13	11	6	18	17	28	22	19	28	26	12	10	15	21
Non-adapted Group	6	10	16	26	31	41	42	36	51	39	32	16	11	8

* Four-trial blocks on Day 3

from Day 2 to Day 3 results from the fact that on Day 3 this group was light-adapted.) The fact that there are no acquisition or extinction trends in the frequency data of the non-adapted group for responses in this latency range strongly suggests that the conditioned responses are to be found in some other latency range.

The frequency of responses in the 250–450 msec. range shows a clear-cut acquisition increment on Day 1 and a clear-cut extinction decrement on Day 3 for the non-adapted group. The average magnitude data followed essentially the same trends as the frequency data of Table V, and Alexander's trend analysis (1) showed that the acquisition and extinction trends within the latency range from 250–450 msec. were statistically significant for the non-adapted group. The data of the dark adapted group do not follow the clear-cut trends of the non-adapted group in the 250–450 msec. latency range. The significance of this is not obvious, but it seems reasonable that the presence of the β-responses in the dark adapted group prevents or obscures the usual acquisition and extinction trends.

Discounting the data of the dark adapted group because of the disturbing presence of β-responses, it might be said that the responses with latencies from 250–450 msec. behave like CR's, and those with latencies from 120–240 msec. do not. This strongly suggests that the CR's are, for the most part, restricted to the latency range from 250–450 msec., and this range has been labelled 'Proper CR Range (?)' in Fig. 1.

Discussion

1. *The relationship between the β-response and eyelid conditioning.*—The findings of the present experiment lead to two definite conclusions as to the relationship between the β-response and the conditioned eyelid response.

First, it seems clear that the CR is not a modified β-response as had been hypothesized (**8**). This conclusion follows from the results on the latency distribution of the eyelid CR reported above. Latencies of β-responses range from 120–240 msec. and form a distinct mode at about 150 msec. (**6, 7, 8, 9**). When sensitization of the β-response was eliminated in the present study, the responses in the latency range showed no appreciable conditioning acquisition or extinction trends. At the same time, the responses with latencies from 250–450 msec. showed clear-cut conditioning trends from the non-adapted group. The β-response and the eyelid CR are thus functionally differentiated with respect to latency and with respect to the effects of dark adaptation, and the conclusion follows that they are different responses of the eyelid action system.[2]

Second, the presence of β-responses during reinforcement has a definite effect upon the conditioning process. The effect in the present experiment was two-fold. Dark adaptation and the presence of β-responses lowered the frequency and magnitude of CR's during the early extinction trials in the dark adapted group, and the usual extinction trend was not present in this group. Instead, there was a rise in frequency and magnitude of the responses *within the proper CR latency range (250–450 msec.)*. It cannot be claimed on the basis of 16 trials that extinction would not occur under these experimental circumstances, but a gross alteration in the extinction process did take place.

2. *Interpretation of influence of β-responses upon the conditioning process.*—The present investigation was not designed to reveal the mechanism through which the conditioning process was altered by the presence of β-responses. Three more or less obvious interpretations will, however, be considered. Any interpretation must, of course, take into account the fact that, since there was no procedural difference between groups on Day 3, simple sensitization on Day 3 is ruled out. The interpretation must be based upon the procedural differences occurring on Days 1 and 2.

[2] It should be pointed out that although the hypothesis that the CR was a modified β-response is to be rejected, the statement that conditioning reinforcement is a dual process in eyelid experiments (**8**) is certainly confirmed, at least with respect to results as published by various investigators. Since many earlier studies included all anticipatory responses as CR's, and since many of these experiments permitted dark adaptation to take place, part of the reported findings are undoubtedly based upon sensitization of the β-response which closely resembles the CR acquisition process (**7**).

One interpretation might involve 'situational' conditioning of the sensitization process. The β-response system in the dark adapted *S* became sensitized on Days 1 and 2; the β-response system mechanism of the non-adapted *S* did not. On Day 3, it is possible that the sensitization process had become conditioned to various redintegrative cues and took place in spite of the absence of dark adaptation. The data of Table V, however, lend little support to such an interpretation. The reversal of the extinction trend takes place for responses in the proper CR range of latencies, and there is no evidence of sensitization in the β-response latency range. In its present form this first interpretation, then, does not fit the facts and must be rejected.

Another explanation might be framed in terms of the greater effective strength of the CS (light) under dark adapted conditions. Stronger conditioning might have occurred in the dark adapted group by virtue of the more intense CS, and this stronger conditioning might have been temporarily obscured on the first few extinction trials of Day 3 by the disrupting effect of the change in lighting arrangements. This explanation must be viewed with caution for two reasons. First of all, the data of Table V suggest that stronger conditioning may not have occurred in the dark adapted group. If it did occur, it was hidden by the presence of the β-responses. Second, although stronger conditioning might be predicted for the stronger CS by Hull's theory (**13**, Ch. 10), the experimental evidence on the point is ambiguous (**12**, pp. 141–143; **4**). At present, it cannot safely be concluded that the intensity of the conditioned stimulus exerts any great influence on the strength of conditioning as measured by extinction. Unless the strength of conditioning can be shown to be affected by the magnitude of the CS, the whole explanation is invalidated.

A third possibility can at present be phrased only in tentative terms. This possibility is that some novel reinforcing effect was present during Days 1 and 2 for *S*s of the dark adapted group. The possibility is admittedly speculative, but it cannot be ignored. Such a novel reinforcing effect might arise when a normal CR is blocked because the eyelid is reopening or is temporarily in refractory phase following a β-response. This situation would, of course, occur almost exclusively in the dark adapted group of the present experiment. The principle required would be almost diametrically the opposite of Guthrie's conception of reinforcement (**10**) and might involve some sort of reserving construct resembling Skinner's 'reflex reserve' (**17**).

3. *General implications for research and theory formulation in conditioning and learning.*—Aside from the specific implications of the findings of the present research, there is pointed up a well-recognized,

but little-heeded, principle of scientific analysis in the field of conditioning and learning. The adaptive effects of learning and conditioning in a given receptor system are functionally related to the original behavioral repertoire of that system. It is rash indeed to base theories and principles of associative learning upon the adaptive alterations in a response system whose original complex characteristics are uncharted. This has been shown again and again in the conditioning literature—in connection with the salivary reflex, the hand-withdrawal response, the knee-jerk, the GSR, the pupillary response, and the eyelid reaction.

Summary

The object of the experiment was to discover the effect of a high frequency of β-responses during reinforcement upon eyelid conditioning. Two groups of *Ss* were run through 25 standard light-puff reinforcement trials on each of two days. This procedure occurred after the 21 *Ss* of the dark adapted group were dark adapted in order to sensitize the β-response mechanism. The 20 *Ss* of the non-adapted group remained light adapted. On the third day, *Ss* of both groups were given 16 standard extinction trials under identical conditions of light adaptation.

The essential findings of the experiment were as follows:

1. The object of dark adaptation and light adaptation was clearly achieved; the frequency of β-responses was maximized in the dark adapted group and minimized in the non-adapted group.
2. The *Ss* of the non-adapted group gave typical acquisition and extinction curves for the frequency and magnitude of CR's.
3. The acquisition curves for *Ss* of the dark adapted group were obscured by the high frequency of β-responses, but the extinction curves reversed the trend usually found with eyelid conditioning. The increases in the frequency and magnitude of the responses which occurred with these *Ss* during extinction were significantly different from the corresponding 'normal' extinction trends in the non-adapted group.
4. The results indicate that under 'standard' experimental arrangements for eyelid conditioning, the CR's are restricted to a latency range of 250–450 msec.

The findings indicated that the eyelid CR was not a modified β-response as had been hypothesized, but that the presence of the β-response during reinforcement had a definite effect upon eyelid conditioning. It was conjectured that the effect might arise through a novel type of reinforcement occurring, perhaps, when the comple-

tion of a newly acquired CR was blocked by the effects of the shorter-latency β-response.

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DARK ADAPTATION AND THE PSEUDO-CONDITIONED EYELID RESPONSE [1]

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The present study was designed to discover whether repetitive corneal puff stimulation or dark adaptation was the significant factor in bringing about sensitization of eyelid responses to light in pseudo-conditioning experiments.

In 1943, Grant (**3**) reported increases in frequency and amplitude of eyelid responses to light following pseudo-conditioning reinforcement. The phenomenon closely resembled conditioning. This finding was later confirmed (**4**), but in both experiments results from control procedures left some doubt as to the role of the air-puff in effecting the increments. This led to the suggestion (**3**, p. 146) that the results be ". . . referred to by means of some such general term as *sensitization* rather than as *pseudo-conditioning*." Dark adaptation of the *S*s was a feature common to the earlier studies; and subsequent experimentation on the secondary response (β-response) of the eyelid to light (**5**, **6**) led to the hypothesis that the 'pseudo-conditioning' frequency increments were, in fact, the sensitization of the β-response mechanism which occurs during dark adaptation.

The present study was planned to test this hypothesis. The experimental design was so arranged that the effects of the two experimental or independent variables, repetitive puff-stimulation, and dark adaptation, and their interaction could be isolated and measured. Thus, it would be possible to learn whether repetitive puff reinforcement had any pseudo-conditioning effect on the eyelid response over and above the effects of dark adaptation.

Apparatus and Procedure

1. *Apparatus.*—The basic stimulating and photographic recording apparatus has been described elsewhere (**1**, **6**). The general methods used to light adapt and dark adapt the *S* were the same as in a previous study (**6**).

Two stimuli were used in the present experiment. One, the light stimulus, consisted of illuminating a 10-cm. circular milk-glass window to a brightness of 270 millilamberts. The duration of the light stimulus was 750 msec. The other stimulus, the air-puff, consisted of a slight puff of air delivered to the right cornea. The two stimuli were never presented together

[1] This research was supported in part by a grant-in-aid from the Graduate School Research Fund of the University of Wisconsin for the year 1945–46.

on the same trial in the present experiment. The interval between trials, except where otherwise stated, was varied randomly from 25 to 45 sec.

2. *Subjects.*—The *S*s were 80 men and women students who volunteered from classes in elementary psychology.

3. *Procedure.*—The experiment was designed to isolate the effects upon eyelid responses of two factors: 1, repetitive puff stimulation or pseudo-conditioning reinforcement, and 2, dark adaptation. To accomplish this the *S*s were divided, on the basis of order of appearance for the experiment, into four groups of 20, each of which was run through different but parallel procedures as shown in Table I.

TABLE I

THE EXPERIMENTAL PROCEDURES

Group I Puff-Adaptation	Group II Puff-Non-adaptation	Group III Fixation-Adaptation	Group IV Fixation Non-adaptation
1. Five min. *light adaptation* for all groups			
2. One min. *dark adaptation* for all groups			
3. *Pre-test*, consisting of four light-stimuli and one control trial, *under identical dark-adaptation conditions for all groups*			
4. Under dark adaptation conditions: 40 pseudo-conditioning trials with the air-puff alone	4. Under constant light conditions designed to *prevent dark* adaptation: 40 pseudo-conditioning trials with the air-puff alone	4. Under dark adaptation conditions: 27 min. of visual fixation; no stimulation	4. Under constant light conditions designed to *prevent* dark adaptation: 27 min. of visual fixation; no stimulation
5. One min. of *dark adaptation* for all groups			
6. *Post-test*, consisting of four light stimuli and one control trial, *under identical dark adapting conditions for all groups*			

First, all *S*s were light adapted for five minutes. Next, followed the pre-test which consisted of four light stimuli and one control trial (3) during which all eyelid responses were recorded. Then followed the experimental procedures which varied from group to group as indicated in Table I. (Assignment of *S*s to the four groups was solely on the basis of their order of appearance.) Finally, after one minute of dark adaptation, the *S*s of all groups were given a *post-test* which was the same as the pre-test, and which was given under identical conditions for all groups.

RESULTS

In the previous eyelid pseudo-conditioning studies (3, 4), all responses within the usual conditioned response (CR) and pseudo-conditioned response (PCR) latency range (120–450 msec.) were included in the analysis. In order that the analysis of the present data would be comparable, eyelid responses in this latency range have been used.[2]

In Table II are given the percent frequency and mean magnitude in mm. of all eyelid responses which fell within the CR and PCR latency range. These data are given for the pre-test and the post-

[2] The experiments on the β-response indicate that the latency range from 120–240 msec. would be better, but either range produces essentially the same findings.

test for each group separately. The frequency data are also presented graphically in Fig. 1 to facilitate interpretation.

TABLE II

AVERAGE FREQUENCY (%) AND AVERAGE MAGNITUDE (MM.) OF EYELID RESPONSES WITHIN THE CR AND PCR LATENCY RANGE (120–450 MSEC.) DURING PRE- AND POST-TESTS

Group	Frequency (%)		Magnitude (Mm.)	
	Pre-Test	Post-Test	Pre-Test	Post-Test
I. Pseudo-conditioning Adaptation	15.0	72.5	0.74	5.30
II. Pseudo-conditioning Non-adaptation	28.7	16.2	1.70	1.72
III. Fixation-Adaptation	25.0	58.7	2.28	4.45
IV. Fixation-Non-adaptation	25.0	32.5	1.31	2.76

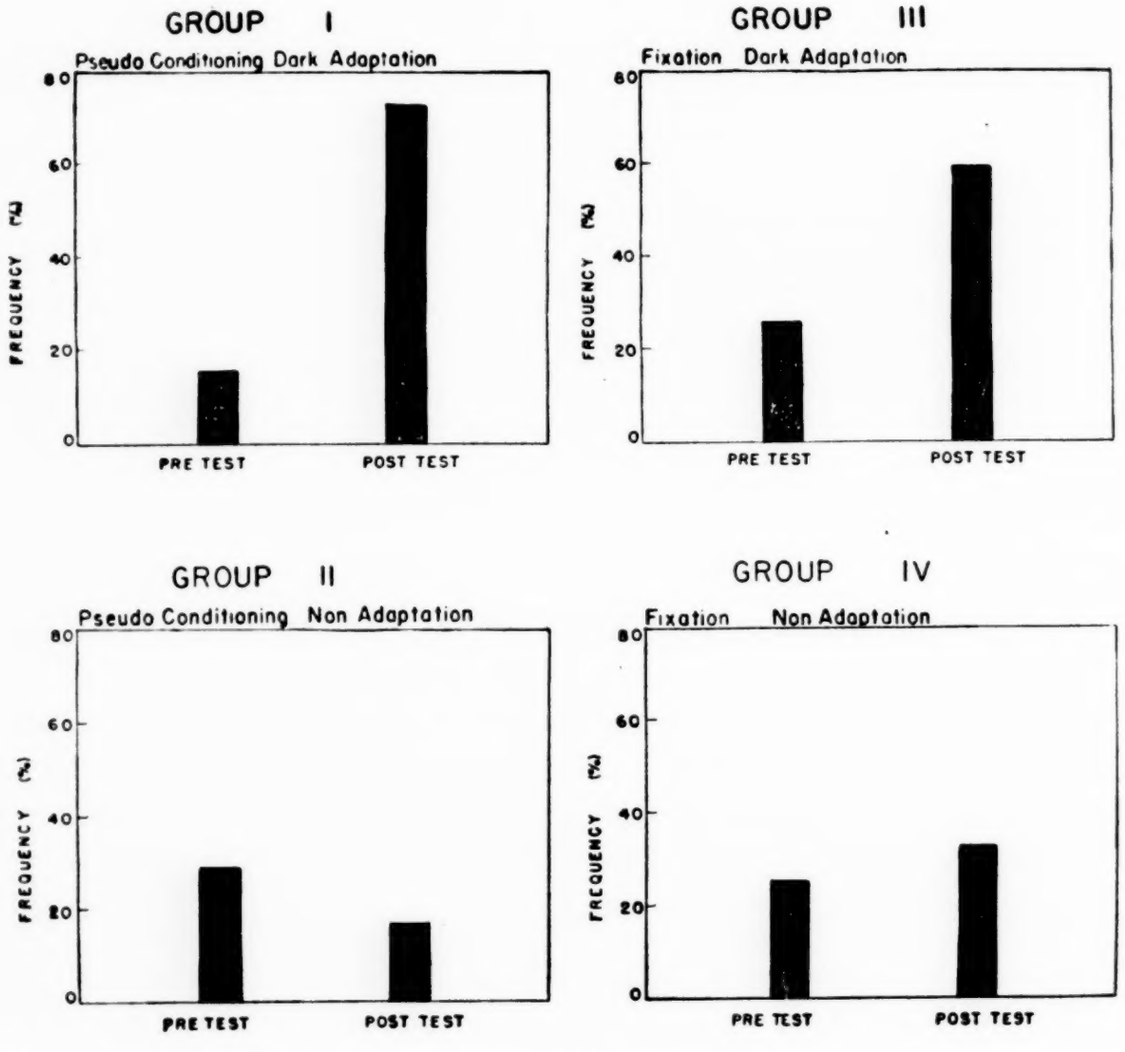

FIG. 1. Percent frequency of eyelid responses with latencies from 120 to 450 msec. which were recorded on the pre-test and post-test of the experiment

Frequency and magnitude increase markedly from pre-test to post-test in Groups I and III, which had dark adaptation as a common factor in procedure. There is a less extensive increase in Group IV, where neither dark adaptation nor pseudo-conditioning reinforcement was given. There is a decrease in frequency and no real change in magnitude in Group II, where pseudo-conditioning reinforcement without dark adaptation was given.

The design of the experiment permits an analysis of variance to test the effects of PCR reinforcement, dark adaptation, and their interaction. This is possible, as is shown schematically in Table III,

TABLE III

SCHEMATIC DESIGN OF THE EXPERIMENT

		Dark Adaptation**	
		Present	Absent
Pseudo-conditioning Reinforcement*	Present	Group I	Group II
	Absent	Group III	Group IV

* Variation between row means shows PCR reinforcement effect.
** Variation between column means shows dark adaptation effect.

because Groups I and II received PCR reinforcement while Groups III and IV did not, and Groups I and III were dark adapted while Groups II and IV were not.

The results on the pre-test showed no significant differences between the four groups. The differences which appeared on the post-tests are best analyzed in terms of shifts from pre-test values. The

TABLE IV

ANALYSIS OF VARIANCE OF FREQUENCY INCREASES IN EYELID RESPONSES FROM PRE-TEST TO POST-TEST

Source of Variation	Sum of Squares	*df*	Mean Square	*F*	*P*
Pseudo-conditioning Reinforcement	0.11	1	0.11	1/21.51	—
Dark Adaptation	74.11	1	74.11	30.62	<.001
Interaction	15.31	1	15.31	6.33	<.05
Replication	183.95	76	2.42		
Total	273.48	79			

analysis of variance of the frequency *increases* is given in Table IV, and a similar analysis of magnitude *increases* is given in Table V.

The analyses give essentially similar results. On the one hand, repetitive puff stimulation alone contributes negligibly to the frequency and magnitude increments as shown by the *F*-tests in the

TABLE V

ANALYSIS OF VARIANCE OF INCREASE IN MEAN MAGNITUDE (MM.) OF EYELID RESPONSES FROM PRE-TEST TO POST-TEST

Source of Variation	Sum of Squares	*df*	Mean Square	*F*	*P*
Pseudo-conditioning Reinforcement	1.95	1	1.95	1/8.09	—
Dark Adaptation	157.08	1	157.08	9.95	<.01
Interaction	83.03	1	83.03	5.26	<.05
Replication	1199.22	76	15.78		
Total	1441.28	79			

first line of the two tables. Dark adaptation, on the other hand' played an important role in both the frequency and the magnitude gains as shown by the highly significant *F*'s for dark adaptation. The marginal significance of the interaction *F*'s means that the repetitive puff stimulation did not affect the eyelid responses of dark adapted *S*s in the same way as it affected the responses of light adapted *S*s.

DISCUSSION OF RESULTS

The results of the present study define rather precisely the role of repetitive puff stimulation in eyelid pseudo-conditioning and point to a plausible interpretation for the puzzling fixation control group findings of previous investigations (**3, 4**).

Within the limits tested, the puff *alone* had little or no sensitizing effect upon eyelid responses in the CR and PCR latency range. Dark adaptation or some closely related factor clearly did sensitize these responses (cf. **6**). These interpretations follow directly from the statistical analysis.[3] The marginally significant interactions indicate that *the puff may facilitate sensitization when combined with dark adaptation* or partially inhibit sensitization under light adaptation conditions, or both. This is in line with the slightly greater frequency gains reported in the previous studies for PCR reinforcement (plus dark adaptation) as opposed to visual fixation (plus dark adaptation) alone.

The results with Groups I and III essentially duplicate the findings of the pseudo-conditioning experiments (**3, 4**). The interpretation of the present experiment, afforded by considering the results of Groups II and IV, as well as the results of Groups I and III, clearly applies to the earlier studies. It is therefore indicated: (*A*)

[3] It cannot, of course, be concluded rigorously that the puff alone had *no* effect; i.e., null hypotheses are never proved. The *F*-test or *t*-test of the analysis of variance, if based on 76 d.f., is very powerful (**2**), and any statistical hypothesis ascribing much effect to pseudo-conditioning reinforcement would be rejected at a high confidence level.

that repetitive puff stimulation alone has little or no pseudo-conditioning effect on the eyelid responses in the CR latency range; (*B*) that pseudo-conditioning of the eyelid responses under the general experimental arrangements reported probably consists of an enhancement of the effects of dark adaptation; and (*C*) the main effects reported earlier were primarily the results of dark adaptation and attendant sensitization processes, and, as suggested in the earlier studies, the phenomena observed might indeed better be referred to as ". . . *sensitization* rather than as *pseudo-conditioning*."

Summary

The effect of (*A*) repetitive puff stimulation and (*B*) dark adaptation upon eyelid responses to light in the latency range of CR's was investigated in four groups of 20 *S*s each. All groups were first pre-tested for eyelid responses to light. Then Groups I and II were given 40 spaced stimulations consisting of puffs of air to the cornea, Groups I and III were dark-adapted, and Groups II and IV maintained light adaptation. Finally all groups were post-tested to discover shifts in frequency and magnitude of eyelid responses to light. The findings of the experiment may be summarized as follows:

1. Dark adaptation effected significant increases in frequency and magnitude of eyelid responses in the CR and PCR latency range, but repetitive puff stimulation (pseudo-conditioning reinforcement) by itself had little or no effect.

2. Repetitive puff stimulation may have facilitated the sensitizing effects of dark adaptation or inhibited tendencies toward sensitization in the absence of dark adaptation.

The influence of dark adaptation in effecting changes in the responses of the eyelid action system was separated from the influence of pseudo-conditioning reinforcement, and the results of previous sensitization experiments were found to be clarified.

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STUDIES OF MOTION SICKNESS: XVI. THE EFFECTS UPON SICKNESS RATES OF WAVES OF VARIOUS FREQUENCIES BUT IDENTICAL ACCELERATION[1]

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A. Introduction and Summary

This is the last of a series of investigations done by means of the vertical accelerator at Wesleyan University.[2] It was designed to discover how motion sickness rates are affected by wave frequency when the accelerations in the waves are held fixed. Using waves with a constant acceleration of 0.20 *g*, frequency was controlled by control of the duration of application of upward and downward accelerations. By this means wave frequencies of 13, 16, 22 and 32 cycles per min. were obtained, having amplitudes of 9 feet, 5 feet 4 in., 2 feet 6 in., and 1 foot 1 in. These frequencies are the same as were used in previous studies in this series, where time between accelerations, level of acceleration and other aspects of the waves were varied. Other significant variables were counterbalanced or controlled. The results on 120 *Ss* showed that sickness varied with the energy per wave; the biggest wave produced the most sickness, the smallest wave the least. The obtained sickness rates were 37, 37, 10 and 7 percent in going from the large slow wave to the small fast wave.

[1] The work described in this paper was done under contracts, recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Wesleyan University, Middletown, Connecticut, and the University of Rochester, Rochester, New York. The studies are now being continued under a contract between the Office of Naval Research and the University of Rochester.

[2] The apparatus has been transferred to and assembled at the University of Rochester.

The corresponding 'sickness indices' (giving double weight to vomiting and single weight to lesser sickness) were: 53, 47, 10 and 7.

The results of the entire series of studies of the dependence of motion sickness on wave-characteristics are reviewed and certain tentative conclusions drawn. It is shown that some waves were 20 times as nauseating as others, per unit of energy, and that such variations depended on at least four factors: wave-duration, acceleration-level, distribution of accelerations and energy per wave.

Data are presented showing the relationship of sickness to hour of the day and to previous history of sickness.

B. Procedures

The general procedures of this experiment were identical (with certain exceptions noted below) with those of previous studies (**1**, **2**, **3**, **4**, **5**, **6**, **7**) and are described in detail in (**1**). In the present experiment 88 Naval Officer-Candidate Trainees and 32 male civilian college students of similar age were used on a wave machine resembling an elevator. The experiment was set up to counterbalance three variables (type of wave, susceptibility of *S*, and time of day) and to control other conditions so far as possible.

1. *Counterbalanced Variables*

We used *S*s of each of three susceptibility grades determined by scores on motion sickness history questionnaires (**6**): grade '1,' susceptible; grade '2,' intermediate; grade '3,' non-susceptible. They were used at each of eight hours of the day: 0800, 0900, 1000, 1100, 1300, 1400, 1500 and 1600 Naval Eastern War Time. Four kinds of 'waves' were used (see paragraph 3 below). One *S* was used at each of the 96 possible combinations of the three variables: wave-type, susceptibility and hour-of-the-day; 88 of the *S*s were Naval Officer-Candidates while eight were civilians. We then wished to increase the size of the experimental group, and due to the fact that we had used up the available pool of navy men, we used 24 civilian *S*s. Six men of susceptibility '1' and six of susceptibility '2' were used with each of the four types of wave, without, however, having complete counterbalancing of hour-of-the-day. (Report No. V in this series has shown that hour-of-the-day is not an important factor in sickness.)

2. *Controlled Conditions*

The 88 Naval Officer-Candidate Trainees, resident in the Wesleyan V-12 Unit, were used as *S*s by cooperation of local naval officers and by permission of the Secretary of the Navy. The 32 male civilian college students were used after clearance by the college physician on grounds of health. Service as *S* was voluntary but among the Trainees few declined to serve. The exposure to the wave machine was for 20 min. or until vomiting took place. The *S* was seated; the ear-eye line was horizontal. He was blindfolded. The air-temperature was 86° F. Each *S* went through the following procedure: (a) on arrival at the Laboratory he had about two min. to get adjusted; (b) performance test practice session consisting of 15 rifle shots at target; (c) repetition of motion sickness inventory; (d) rifle-target test—15 shots; (e) instructions about wave machine, especially as to certain observations to be made on the apparent path of movement; (f) *wave machine exposure* of 20 min. or less; (g) three min. rest and questions about nausea; (h) rifle-target test—15 shots; (i) *S*'s report on apparent path of motion; (j) interview on history of motion sickness. The data of the rifle performance are reported elsewhere (**8**).

The experiment was conducted between December 13, 1944, and February 13, 1945.

3. *Nature of the Motions*

The motions were like those of an elevator in which the controls are reversed each time as the cab reaches its full upward or full downward velocity, so that it is in continuous up and down motion. The reversal of controls was automatically produced by switches. The controls were

so arranged that during the upper half-wave a *constant* downward acceleration of 0.20 *g* was applied; during the lower half-wave, an equal constant upward acceleration. (It should also be noted that a period of 0.22 sec. was required to reverse controls at the middle of the wave; during this period the cab was not accelerated so it was at constant velocity.) The four wave-types were obtained by controlling the terminal velocity the cab could reach, and therefore (since acceleration was constant at 0.20 *g*) achieving control of the length of time required to reach this velocity and thus controlling wave frequency.

Table I shows the physical characteristics of the waves. Condition J′ is identical with condition J of our third experiment (3). The relative energies per wave shown on line 4 are calculations from the approximate total time of acceleration of each wave-type. The J′ wave is taken as 100 percent; the others, being faster waves, have less total time per wave spent in acceleration.

TABLE I

CHARACTERISTICS OF WAVES

(Approximate)

1. Code letter of wave	J′	P	Q	R
2. Cycles per minute	13	16	22	32
3. Total amplitude of wave (ft. and in.)	9′0″	5′4″	2′6″	1′1″
4. Relative energy per wave	100%	79%	55%	33%

4. *Measures of Sickness*

As in our previous studies, we recorded two grades of sickness and used three criteria for the evaluation of the effects of the experimental conditions: *Criterion* 1 = frequency of vomiting; *Criterion* 2 = frequency of vomiting, *plus* frequency of lesser sickness as indicated by unequivocal reports of nausea and/or profuse sweating (rolling drops) on the face; *Criterion* 3 = vomiting weighted 2, *plus* nausea and/or sweating (as above) weighted 1. In order to facilitate comparisons between experiments having different numbers of *S*s we also converted Criterion 3 to a Sickness Index, $\frac{\text{Criterion 3} \times 100}{\text{No. of cases}}$.

C. RESULTS

The influence of the four wave-types upon sickness rates is shown by the results displayed in Table II and by the estimates of statistical reliability of obtained differences presented in Table III. According to the obtained results the J′ condition (slowest wave, largest energy

TABLE II

EFFECTS OF WAVE FREQUENCY UPON MOTION SICKNESS

(120 *S*s)

Type of Motion (See Table I)	Nausea and/or Sweating		*Criterion* 1 Vomiting		*Criterion* 2 Vomiting *plus* Nausea and/or Sweating		*Criterion* 3 Vomiting = 2 *plus* Nausea or Sweating = 1	Sickness Index
	No. of Cases	% of 30 Cases	No. of Cases	% of 30 Cases	No. of Cases	% of 30 Cases		
J′	6	20	5	17	11	37	16	53
P	8	27	3	10	11	37	14	47
Q	3	10	0	0	3	10	3	10
R	2	7	0	0	2	7	2	7
Totals	19	16%*	8	7%*	27	23%*	9	29

* Percent of 120 cases

TABLE III

RELIABILITY OF OBTAINED DIFFERENCES

Waves being Compared	*Criterion* 1 Critical Ratio	*Criterion* 2 Critical Ratio	*Criterion* 3 Critical Ratio
J′ *vs* P	0.76	0.00	0.36
J′ *vs* Q	2.44	2.98	2.89
J′ *vs* R	2.44	3.06	3.18
P *vs* Q	1.82	2.98	2.69
P *vs* R	1.82	3.06	3.01
Q *vs* R	0.00	0.69	0.47

per wave) produced the most sickness, the P condition (next faster wave) a little less, the Q condition considerably less and the R condition (fastest wave, smallest energy per wave) the least sickness. The differences between J′ and Q or R and between P and Q or R are reliable according to conventional statistical standards. The differences between J′ and P and between Q and R are not statistically reliable.

The influence of another of the counterbalanced variables, susceptibility of the *S*, is shown by the results displayed in Table IV.

TABLE IV

RELATION OF MOTION SICKNESS TO SUSCEPTIBILITY CATEGORY
(120 *Ss*)

Susceptibility Category	No. of Cases	*Criterion* 1	*Criterion* 2	Sickness Index
1 (suscept.)	32	13%	34%	47
2 (interm.)	32	9%	16%	25
3 (non-susc.)	32	0%	9%	9
1 (suscep.)	12	8%	42%	50
2 (interm.)	12	0%	25%	25

The table is divided into two sections, the first showing the results of the first 96 *Ss* which include 32 men from each of three grades of susceptibility, the second showing the results of the last 24 *Ss* which include 12 men from each of the two susceptible categories. The results confirm those of our previous studies (**6**) in that the sickness rates were larger in the susceptible categories. The results of the groups of 96 and 24 were similar. Since these results are consistent with expectation, it gives added confidence to acceptance of the results as they relate to wave frequency, for the same data are involved.

The incidence of sickness at each of the eight hours of the experimental day was calculated for the first 96 cases where all variables had been counterbalanced or controlled. The data are displayed in Table V. These may be added to the data already published (**5**),

TABLE V

FREQUENCIES AND AMOUNT OF SICKNESS AT EACH EXPERIMENTAL HOUR
(96 *Ss*, 12 at each hour)

Hour	*Criterion* 1 Vomited	*Criterion* 2 Vomited + Sweat or Nausea	*Criterion* 3 Vomited = 2 N or S = 1	Sickness Index
0800	0	3	3	25
0900	2	4	6	50
1000	2	2	4	33
1100	1	3	4	33
1300	0	2	2	17
1400	0	0	0	0
1500	1	2	3	25
1600	1	3	4	33

being comparable to those appearing in Table 2 of that previous report. They reveal no obvious relationships to meal-time or to period of the day.

D. Discussion and Conclusions

In this study sickness rates decreased as wave frequency increased (Sickness Indices = 53, 47, 10 and 7 for waves of 13, 16, 22 and 32 cycles per min.). This decrease cannot be attributed to total energy expended on the *Ss*, since this was roughly constant. (The *Ss* were under an almost continuous acceleration of 0.20 *g*.) Nor can it be attributed to acceleration-level, which was also constant for all waves. It must therefore be attributed either to the time-character of the waves or to the energy per wave, since these were the variables. It does not seem possible to attribute it wholly to their time-character. Studies I and III (see Table VI) showed maximum sickness for waves of 16 and 22 cycles per min., while this study placed the maximum at 13 cycles. Energy per wave must, therefore, be a significant factor in production of sickness. But this study does not allow us to deny that wave-duration played a part, since the 16-cycle D-wave produced a fairly high sickness index (47), which is not reliably smaller than that (53) produced by the 13-cycle J′-wave.

The interpretation of the results of the present study may best be put in the context of the results of our four previous studies of the influence of wave-characteristics upon sickness rates (**1**, **2**, **3**, **4**). In this series of five investigations we have controlled or varied four aspects of the waves:

1. The rate of work done during the exposure period (wave energy × wave frequency).
2. The energy per wave.
3. The time per wave (cycling rate).
4. Acceleration-level and wave-form.

TABLE VI

SUMMARY OF THE EFFECTS OF SIXTEEN TYPES OF WAVES UPON MOTION SICKNESS RATES

Code Letter of Wave	Rate of Work in Percent, with A-wave as Reference Level. Approx.	Energy per Wave in Percent with A-wave as Reference Level. Approx.	Time per Wave as Indicated by *Cycles per Min.*	Acceleration Level or Levels Used	Sickness Index	Reference to Bibliography
A	100%	100%	32	0.65g	10	1
B	69%	100%	22	0.65g	47	1
C	50%	100%	16	0.65g	63	1
D	41%	100%	13	0.65g	37	1
B′	69%	100%	22	0.65g	33	2
E	52%	75%	22	0.65g	23	2
F	31%	50%	20	0.65g	10	2
A′	100%	100%	32	0.65g	20	3
G	69%	100%	22	0.36g	77	3
H	50%	100%	16	0.25g	63	3
J	41%	100%	13	0.20g	53	3
H′	50%	100%	16	0.25g	82	4
K	50%	100%	16	0.65/0.17g	15	4
L	50%	100%	16	0.17/0.65g	30	4
M	65%	100%	21	0.65/0.25g	38	4
N	65%	100%	21	0.25/0.65g	42	4
J′	41%	100%	13	0.20g	53	This paper
P	40%	79%	16	0.20g	47	This paper
Q	38%	55%	22	0.20g	10	This paper
R	35%	33%	32	0.20g	7	This paper

While our series of investigations is incomplete from the scientific point of view, so that no final conclusions yet seem justified, nevertheless some tentative conclusions should be drawn. To facilitate comparison of the effects of the variables named above, we have drawn up a summary table showing the obtained sickness rates (using the Sickness Index) along with some physical characteristics of the waves. (Reference to the original papers will be required for a full statement of wave-characteristics and sickness rates.) We will discuss the influence of wave-character in the order, time-characteristics, acceleration-levels, rate of work, and energy per wave, after a brief consideration of certain assumptions entering into our thinking.

It seems most reasonable to regard the motion-sick state as an accumulative phenomenon. Presumably certain centers within the nervous system are stimulated into activity by motion receptors. We may further assume that such central activity would, in the absence of continued stimulation, show a gradual decrement. Overt sickness, according to this view, is the consequence of a rate of stimulation (or increment) which exceeds the rate of decrement.

If these assumptions are accepted, one would seem to be led to the position that each wave (or half-wave) can make a certain contribution to the central activity which eventually results in sickness. We shall therefore be interested both in sickness-producing capacity per wave and in the total number of waves required to produce sickness.

Time per wave (cycling rate) was varied in the first, third and present studies; it was held constant in the second and fourth studies. The first study, however, has the most direct bearing on our interpretation of wave-duration as a variable. In this study, acceleration-level and energy per wave were held constant, while time per wave and rate of work varied. The obtained results showed that a certain intermediate wave-duration and rate of work yielded maximum sickness. This leads to the question whether wave-duration or rate of work was the significant factor. If we accept our initial assumption (above) that the sick state is accumulative, each wave producing an increment, it would be improper to attribute the obtained results to the work rates, since sickness did not increase (but decreased) with work rate. Wave-duration is, then, the significant variable. There appears to be an optimum duration for the given set of conditions.

Acceleration-level was held constant in the first, second and present experiments; it was varied in the third and fourth. (The first-named studies showed that sickness can vary enormously while acceleration is constant. The present study, in particular, shows that sickness varies under constant acceleration even when the rate of work is roughly constant.) The third study duplicated the first in respect to wave-durations, energy per wave and work rates, but allowed acceleration to vary with wave-duration. The results, in general, paralleled those of the first study except that the obtained sickness rates from slow waves with low accelerations were greater than from the first study's slow waves with high accelerations. It was therefore concluded that acceleration is a significant factor. This was further confirmed by the fourth study, in which acceleration was the only variable, rate of work, energy per wave and total wave-duration being held constant. Sickness rates were thereby shown to be affected by the nature of the acceleration in a wave.

Energy per wave was held constant in the first, third and fourth studies; it was varied in the second and present study. The second study held constant acceleration and (roughly) wave-duration, while energy per wave and rate of work were allowed to vary. Sickness decreased as the two latter decreased. The present study held constant acceleration and (roughly) rate of work, while energy per wave

and wave-duration were allowed to vary. It is obvious from the obtained results that energy per wave is a factor in sickness. Sickness was found to decrease with energy per wave although rate of energy was held roughly constant. Furthermore, this decrease cannot be attributed wholly to the other variable (wave-duration), since the variation of sickness with wave-duration does not follow the form previously found in the first and third studies.

Rate of work was varied in the first three experiments and was held constant in the last two. In the second experiment rate of work varied with energy per wave and obtained sickness varied in the same way. Taken alone, therefore, it does not allow us to attribute the sickness to one or the other. In the first and third studies rate of work varied as wave-duration varied. Because intermediate work values yielded maximum sickness, we attribute the major features of the obtained results to wave-duration and to acceleration-level rather than to rate of work, which we assume should bear a uni-directional relationship to sickness. The fourth experiment (in which rate of work was held constant) has no direct bearing on establishing the role of rate of work, except as further proof that it is not the only significant variable. But the present experiment has a most important bearing, since rate of work was held (roughly) constant yet sickness varied. We therefore conclude that rate of work (considered independently of the character of the waves that contribute to it) has not been shown to be a significant variable.

In general conclusion, then, it would appear that the capacity of a wave to induce sickness depends on wave-duration, acceleration-level, wave-form, and energy per wave. It is clear that the effect of any one of these variables depends upon its context with the others. We have obtained enormous differences in the nauseating properties of waves. The H and H′ waves, for instance, are roughly 20 times as nauseating per unit of energy as are the A and A′ waves.

The elucidation of the receptor mechanics or of the central nervous system physiology which underlies these differences in wave effectiveness must wait upon further studies. It is our hope to investigate the relationship of wave-characteristics to sickness for other wave-forms (especially sinusoidal) using human *Ss*, and to extend our studies to dogs preparatory to physiological studies. We are especially eager to undertake eighth nerve action potential studies in relation to wave-characteristics.[3]

(Manuscript received October 16, 1946)

[3] Further studies of animals and humans are now in progress under contract with the Office of Naval Research. G. R. W. Sept. 19, 1947, University of Rochester.

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AN ANALYSIS OF THE APPROPRIATE UNIT FOR USE IN THE MEASUREMENT OF LEVEL OF GALVANIC SKIN RESISTANCE [1]

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Introduction

The electrical resistance of the skin may be specified in many ways. To mention three obvious possibilities, it may be stated in terms of resistance as such, in terms of conductance, or in terms of the logarithm of resistance. It is to be noted that any one of such a set of measures may be converted into any other—e.g., if an *S*'s conductance is known, his resistance and log resistance may be directly calculated. Units interrelated in this fashion are thus fundamentally equivalent. In the final analysis an *E* is free to employ whichever one he chooses.

This equivalence in the essential meaning of such units, however, does not imply that all are equally satisfactory for experimental purposes. In particular, it is highly desirable for ease in data analysis that a unit shall provide measurements amenable to statistical treatment. And, since almost all conventional statistical techniques assume a normally-distributed parent population, this imples that an appropriate unit must provide a set of measurements not deviating significantly from normality. The requirement of distribution normality thus may be used as a criterion for the selection of an acceptable unit.

The measures which may possibly prove appropriate include the three obvious candidates already mentioned—resistance (R), conductance (C), and log resistance (log R). To these may be added the square root of $R(\sqrt{R})$, and the square root of $C(\sqrt{C})$, which also may be computed with ease. Of course the possibilities are not exhausted by these five measures. Indeed, there are indefinitely many candidates, as may easily be recognized by considering the possibilities

[1] This research was supported in part by funds granted by the University of Alabama Research Committee.

[2] A preliminary report of this material was presented by the writer at the 1946 meetings of the Southern Society for Philosophy and Psychology.

inherent in the use of roots and powers alone.[3] If, however, resistance, or one of its simple transforms, is acceptable then there is no need to look further. It was our purpose to determine which, if any, of these five possible units might prove appropriate in the sense of providing a normally-distributed set of measurements.

This problem does not seem to have been subjected to previous experimental attack. Haggard (**3**), however, has recently considered a rather similar question for the galvanic skin response. His results lead him to conclude that the unit of measurement appropriate for the GSR is the logarithm of R plus a constant k, all divided by the general level of resistance. He suggests further that in dealing with the general *level* of skin resistance "one should first translate the data into the logarithm of the level scores." This suggestion, however, must be recognized as tentative, since the evidence presented concerns short time changes in skin resistance—i.e., the GSR—rather than level as such. The unit Haggard proposes is included, of course, in our list of candidates for investigation.

Method and Procedure

The experimental design involves two steps which are logically separate. The first step is entirely obvious. The resistance levels of a number of *Ss* were obtained, and the distributions provided by the five units under consideration were checked for normality. The second step consisted of a remeasurement of the level of some of the *Ss*, and an examination of the populations of intra-individual differences between the first and second levels as measured in terms of each of the units. This procedure was introduced in order to check the adequacy of the various units for use in the highly efficient type of experimental design which makes use of each individual as his own control. For example, the effect of benzedrine upon level of resistance would be determined by measuring resistance levels with and without the drug *in the same Ss*. The statistical analysis would then be made upon the population of intra-individual differences—the obscuring effect of inter-individual variation so being eliminated. It is desirable, therefore, that a unit provide a normal distribution not only of levels as such but also of intra-individual differences in level. Our experimental procedure was designed to provide a check upon both of these points.

The method in brief was as follows: The resistance levels of 78 women *Ss* obtained from an elementary psychology class were measured. These *Ss* fell into four groups according to the days upon which the measurements were made. Group I was composed of 19 *Ss*; group II of 13; group III of 29; and group IV of 18. The first two groups were measured on two consecutive days for the purpose of obtaining a distribution of differences in general level; the remaining two groups were measured only once. The resistance level of each *S*, for each day of measurement, was transformed into the various units mentioned above. The distributions of original level and of differences in level were analyzed for normality by computing the familiar g_1 and g_2 statistics, g_1 indicating skewness, and g_2 kurtosis (**4**, pp. 147–151).

The experimental details were as follows:

1. Apparatus—The circuit used in measuring skin resistance is shown in Fig. 1. The essential elements represented in this circuit are: a dry battery with an E.M.F. of 12 volts, a decade resistance box (range zero to 111,100 ohms), and a microammeter with a range of zero to 150

[3] It is interesting to note, however, that the addition of log C would be redundant here. This measure is obtainable from log R by straightforward multiplication and addition of a constant. The shape of the distribution curve for log C is, therefore, always identical with the shape of the curve for log R.

amperes. The *S* is connected into the circuit by means of two Darrow Universal Electrodes filled with Sanborn Redux Electrode Paste.

In using the apparatus, the current through the *S* is set at 100 microamperes by appropriate manipulation of the resistance box. The *S*'s resistance is then obtained by direct subtraction of the resistance contributed by the resistance box from the total resistance of the circuit. The total circuit resistance is, of course, computed once and for all by dividing the E.M.F. of the battery by the standard current—i.e., in this case, 12 divided by 10^{-4} = 120,000 ohms.

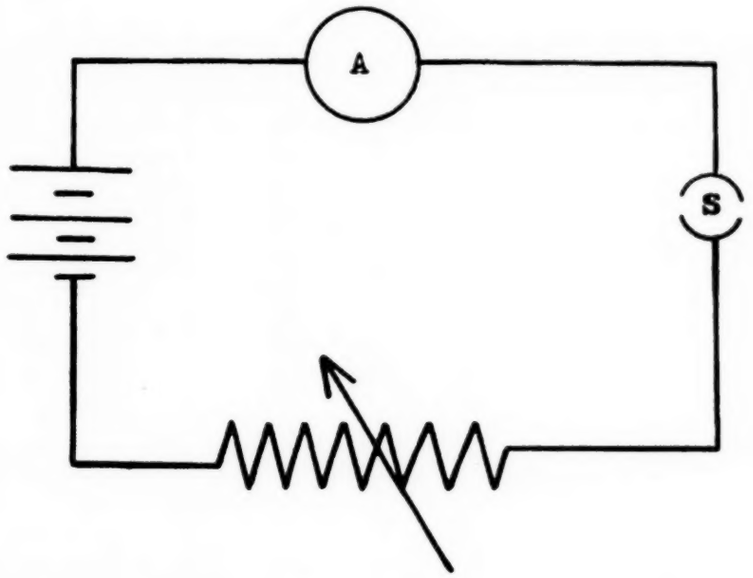

FIG. 1. Diagram of circuit used to measure skin resistance

Operation of the apparatus is simple. The *E* merely observes the needle of the microammeter and manipulates the resistance box to hold this indicator steady at 100 microamperes. This manipulation is easily accomplished with an error not exceeding 500 ohms on any single reading by use of 1000-ohm control alone.

2. Experimental procedure—Each *S* was comfortably seated in a chair, and the following instructions were read to her:

> We are interested in obtaining a set of measures of skin resistance for the purpose of determining which of several possible units of measurement may be best. A *very* weak electric current will be passed through the palms of your hands. It will not be painful in any way—indeed you will not even feel it.

At this point the electrodes were attached to the palms of the hands and the instructions continued:

> Now let your hands relax and dangle over the ends of the chair arms. Close your eyes and relax. . . . All right, close your eyes and relax.

The apparatus was then turned on and after one min. readings were taken at 15-sec. intervals for one min. The average of these five readings was then taken as the *S*'s resistance level for the day.

Upon the second session for any *S* the procedure was similar except for a shortening of the instructions to the information that everything would be the same as before and a repetition of the instruction to close the eyes and relax.

3. Experimental conditions—All measurements were made between 2 P.M. and 6 P.M. In the cases where the level was determined on two consecutive days, the two times of measurement did not differ by more than one-half hour for any *S*.

For groups II, III, and IV the room temperature ranged between 72° and 74° F. For Group I the temperature upon the first day of measurement was 78° F. and upon the second day of measurement was 72° F.

Results

The raw data are presented in Table I.

TABLE I

Resistance Levels of Four Groups of Ss (in hundreds of ohms)

Group I		Group II		Group III	Group IV
Day 1	Day 2	Day 1	Day 2	Day 1	Day 1
170	200	146	172	426	300
184	196	118	138	174	202
220	252	198	214	196	178
210	310	238	220	246	272
198	190	212	204	212	190
270	256	256	240	164	174
222	240	276	178	154	202
204	210	276	150	126	184
190	192	218	186	148	184
202	220	228	180	280	190
264	280	190	230	214	160
134	156	242	—	166	286
254	492	176	—	148	184
134	156			168	354
166	200			140	236
148	166			210	170
160	170			244	122
192	186			240	228
154	156			182	
				174	
				194	
				132	
				126	
				158	
				218	
				210	
				216	
				264	

The results of analysis [4] of these data are shown in Tables II–VII. We shall deal with them in two major sections, the first concerned with the levels as such, the second concerned with the population of intra-individual differences between levels.

1. Levels:

With respect to the distribution of the original levels, information is provided by two sets of results: (a) the distribution of general levels for all groups upon the *first day* of measurement; and (b) the distribution of general levels for groups I and II upon the *second day* of measurement.

[4] The writer wishes to thank Miss Marilyn Rhea, a major in the Department of Psychology of the University of Alabama, for her careful checking of the computations involved in the statistical analysis.

a. First day—

A preliminary analysis of the levels obtained upon the first day showed the four groups to be essentially homogeneous. Neither the means nor the variances differ significantly for any pair of these groups for this particular day. Since this is so, the data were combined and analyzed, with the results shown in Table II. The distributions of C, log R, and $\sqrt{C}$ fulfill the requirements for normality. The distributions of R and $\sqrt{R}$ deviate significantly with respect to both skewness and kurtosis.

TABLE II

SKEWNESS (g_1) AND KURTOSIS (g_2) OF THE TOTAL DISTRIBUTION OF DAY 1 SCORES AS MEASURED IN TERMS OF RESISTANCE (R), CONDUCTANCE (C), LOGARITHM OF RESISTANCE (LOG R), SQUARE ROOT OF RESISTANCE ($\sqrt{R}$), AND SQUARE ROOT OF CONDUCTANCE ($\sqrt{C}$)

	R	C	log R	$\sqrt{R}$	$\sqrt{C}$
g_1	−1.25	0.42	0.30	0.72	0.09
t	4.60	1.55	1.08	2.64	0.33
P	<.01*	.1<P<.2	.2<P<.3	<.01*	.7<P<.8
g_2	3.16	0.05	−0.33	1.30	−0.07
t	5.88	0.09	0.61	2.41	0.13
P	<.01*	>.9	.5<P<.6	.01<P<.02*	.8<P<.9

* Indicating a significant deviation from normality.

b. Second day—

In dealing with day two, combination of results from groups I and II unfortunately is not possible since these two groups deviate significantly in mean level. The data from each group have therefore been analyzed separately with the results shown in Tables III and IV.

TABLE III

SKEWNESS OF DAY 2 DISTRIBUTIONS OF GROUPS I AND II TREATED SEPARATELY, AND COMBINED PROBABILITY

Group		R	C	log R	$\sqrt{R}$	$\sqrt{C}$
I	g_1	−10.26	0.63	1.48	1.99	−1.04
	t	19.59	1.21	2.83	3.79	1.99
	P	<.01*	.2<P<.3	<.01*	<.01*	.02<P<.05*
II	g_1	0.16	0.74	−0.44	−0.24	0.57
	t	0.24	1.12	0.66	0.36	0.86
	P	.8<P<.9	.2<P<.3	.5<P<.6	.7<P<.8	.3<P<.4
Probability of compound event **		<.01*	.1<P<.2	.05<P<.1	<.01*	.1<P<.2

** The combination of probabilities has been made following the technique described by Fisher (2, pp. 104–106).

TABLE IV

KURTOSIS OF DAY 2 DISTRIBUTIONS OF GROUPS I AND II TREATED SEPARATELY, AND COMBINED PROBABILITY

Group		R	C	log R	$\sqrt{R}$	$\sqrt{C}$
I	g_2	26.89	0.31	3.02	5.19	1.42
	t	26.52	0.31	2.98	5.12	1.40
	P	<.01*	.7<P<.8	<.01*	<.01*	.1<P<.2
II	g_2	−0.90	−0.09	−0.58	−0.87	−0.40
	t	0.70	0.07	0.46	0.58	0.32
	P	.4<P<.5	>.9	.6<P<.7	.5<P<.6	.7<P<.8
Probability of compound event		<.01*	.5<P<.6	<.01*	<.01*	.3<P<.4

As the tables indicate, the distributions of C and $\sqrt{C}$ fulfill both normality requirements. The distribution of log R shows a degree of skewness just below the five percent level of significance, and a degree of kurtosis slightly above the one percent level of significance.

From these results it appears that C and $\sqrt{C}$ are satisfactory units for specification of level. It seems possible that log R may also be acceptable for most purposes, since its distribution fulfills requirements of normality for the large group of 78 cases and does not deviate enormously for the two smaller groups measured on the second day.

2. Differences in Level:

We proceed now with the analysis of the population of intra-individual differences. When measured by an appropriate unit this population should fulfill two requirements: As has been indicated, the differences should distribute normally. In addition, it seems desirable also that the differences should be independent of the original levels of the *S*s. The fulfillment of this second requirement will then make possible direct comparison of *changes* in level in different *S*s.

In checking the normality of this population separate treatment of the two groups is again required, since the means differ significantly. The results of analysis appear in Tables V and VI. As these tables show, the distribution of C, and only of C, fulfills the conditions of normality.

The possibility of a dependence of the change in level upon the original level itself was checked by correlating these two variables. The correlations for each unit are shown in Table VII. As the table indicates, none of the correlations approaches significance. So far as our evidence is concerned then, all of the units are acceptable in this respect.

TABLE V

SKEWNESS OF DISTRIBUTIONS OF DIFFERENCES AND COMBINED PROBABILITY

Group		R	C	log R	$\sqrt{R}$	$\sqrt{C}$
I	g_1	3.26	0.79	2.23	2.83	1.50
	t	6.23	1.50	4.27	5.40	2.87
	P	<.01*	.1<P<.2	<.01*	<.01*	.01<P<.02*
II	g_1	0.95	0.74	0.88	0.91	0.82
	t	1.44	1.12	1.32	1.38	1.24
	P	.1<P<.2	.2<P<.3	.2<P<.3	.1<P<.2	.2<P<.3
Probability of compound event		<.01*	.1<P<.2	<.01*	<.01*	<.01*

TABLE VI

KURTOSIS OF DISTRIBUTIONS OF DIFFERENCES, AND COMBINED PROBABILITY

Group		R	C	log R	$\sqrt{R}$	$\sqrt{C}$
I	g_2	11.73	0.16	6.08	9.16	2.83
	t	11.56	0.15	6.00	9.03	2.79
	P	<.01*	.8<P<.9	<.01*	<.01*	<.01*
II	g_2	0.25	0.15	0.17	0.20	0.15
	t	0.20	0.11	0.13	0.16	0.12
	P	.8<P<.9	>.9	.8<P<.9	.8<P<.9	>.9
Probability of compound event		<.01*	>.9	<.01*	<.01*	<.01*

TABLE VII

CORRELATION COEFFICIENTS BETWEEN CHANGE AND ORIGINAL LEVEL

Group		R	C	log R	$\sqrt{R}$	$\sqrt{C}$
I	r	0.29	0.18	0.13	0.23	0.01
	r 5%	0.46	0.46	0.46	0. 6	0.46
II	r	−0.08	−0.08	0.08	0.08	−0.08
	r 5%	0.60	0.60	0.60	0.60	0.60
Combined**	r	0.18	0.09	0.11	0.19	−0.02
	r 5%	0.38	0.38	0.38	0.38	0.38

** The combined correlation coefficients have been obtained by the method described by Fisher (2, pp. 209–210).

It seems clear that for specification of *changes* in general level C is the only acceptable measure.

DISCUSSION

The foregoing statistical analysis would seem to justify the following conclusions:

1. C is a satisfactory unit of measurement for specification both of general level and of differences in level.

2. $\sqrt{C}$, and possibly log R, are acceptable as units for specification of general level but are inappropriate for dealing with changes in level.

3. R and $\sqrt{R}$ are inappropriate for either purpose.

These conclusions appear quite straightforward. Three general precautionary points, however, seem worthy of mention:

1. We cannot claim to have *proved* that the units found acceptable are normally distributed—rather, as in all cases of statistical sampling, all that can be said is that the particular hypothesis (in this case, of distribution normality) is not violated significantly. Since, however, we have 77 degrees of freedom for examination of general level and 30 for examination of differences in level, it would appear that a fair chance has been given for the detection of any considerable deviation from distribution normality. It would seem safe to conclude, therefore, that whatever deviations from normality may exist in the distributions of these units must be relatively unimportant, and thus that the application of ordinary statistical treatments will introduce no significant error. Particularly would this be so for such experimental problems as comparisons of means in which, as is well known, the distribution of the variable under consideration tends toward normality with increasing numbers of cases, regardless of the distribution of the parent population of individual items.

2. The results are not to be interpreted as implying that C (or, in some cases, $\sqrt{C}$) is compulsory as the unit of measurement. As we have previously indicated, an E is free to use whatever well-defined unit he chooses, *provided* he applies an appropriate statistical technique for testing the significance of his results. For example, Festinger's test (1) for evaluating the significance of differences between samples from skewed populations might be satisfactory in some instances. If, however, some unit other than those found acceptable here is chosen, then it is compulsory that the E show that his sets of measurements do not violate the underlying assumptions of whatever statistical technique he employs. The units found acceptable here, on the other hand, may be used with reasonable assurance that the commoner types of statistical treatment are appropriate.

3. It should be emphasized that our results are specific to the question of measurements of general level and of relatively long-time changes in level. The conclusions cannot be taken as necessarily applicable to the problem of the unit of measurement for the short-time changes of the GSR.

To recapitulate: For the purpose of measuring general level and intra-individual differences in level, *C* would appear to be the most satisfactory unit. Other units, however, may be acceptable provided appropriate statistical techniques are applied. The conclusions must be considered as limited specifically to the question of measurement of levels and relatively long-time changes in levels.

Summary

The palmar skin resistance levels of 78 *S*s were determined in an effort to discover which of several possible units for specifying general *levels* of resistance might be appropriate. The units investigated were: resistance as such, conductance, log resistance, square root of resistance, and square root of conductance. The principal criterion of acceptability of a unit was the requirement that the distribution of measures in terms of the unit should not violate the assumption of normality in the parent population (thus ensuring the amenability of results so specified to the usual types of statistical treatment). The results obtained indicate that conductance is the most satisfactory unit of measurement for specification of general levels of skin resistance.

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